MAKING SMART URBAN DECISIONS: THE NICHE OF A PARAMETRIC SPATIAL MODEL TO BALANCE THE NEEDS OF URBAN STORMWATER MANAGEMENT AND HUMAN WELLBEING

J. Jia[1]*, S. Zlatanova[1], S. Hawken[1], K.F. Zhang[2]

[1] School of Built Environment,UNSW, Sydney, New South Wales, Australia - (jing.jia.1, s.zlatanova, s.hawken)@unsw.edu.au
[2] School of Civil and Environmental Engineering,UNSW, Sydney, New South Wales, Australia - kefeng.Zhang@unsw.edu.au

Commission IV

KEY WORDS: Urban Space, Sustainable Stormwater Management, Human Wellbeing, Parametric spatial model

ABSTRACT:

Rapid urbanization has resulted in high-density construction, more impervious area and with increasing threats of urban stormwater, drought and negative influences on human wellbeing. Although there has been progress in sustainable stormwater management and the promotion of human wellbeing with green space, the research has been conducted from a mono-disciplinary perspective and has brought potential conflicts in the utilisation of green space in an urban area. Since smart city proposed, researchers are exploring informational and integrated urban management to face this type of development conflicts and achieve a harmonious and sustainable future. This research proposes a parametric spatial model to integrate stormwater management and human recreation needs based on the understanding of the relationship between them on the same urban green space. We expect that this integrated parametric spatial model will help residents to interact with functional green space and provide options to organize the urban green space smarter and more effectively. This paper presents: (1) A review of the main sustainable stormwater management measures with principles, models and facilities to reveal an overlooked but important relationship between space and stormwater management. (2) Investigation of the research on the benefits of green space on human wellbeing. The study argues that the participation of green space cannot be effectively and accurately analysed with the current main analysis measures which relying on satellite-based vegetation indices or land-use database. This research is intended to set smarter decision making on urban green spaces which connects sustainable stormwater management with human wellbeing via visualised parametric spatial model.

1. INSTRUCTION

Rapid urbanisation is pushing the intensive urban construction by occupying the existing green area which has brought several issues to further urban development, such as rampant urban stormwater disasters (Kimmelman, 2017, Ignacio et al., 2018), water drought threatens (University of Oxford, 2019) even growing human mental ills (Mechelli, 2019). Following rapid urban construction, urban floods have caused billions of dollars of loss per year and even taken lives (Ignacio et al., 2018). The 2012 summer urban flooding in Beijing has taken 79 people's lives (Xu, 2012, Li et al., 2016). 2001 storm in Seoul left at least 49 people dead (Xu, 2012). These problems are more obvious in more densely settlement area, such as coastal cities (McGranahan et al., 2007). The progress report of Sustainable Development Goals (SDGs)-goal 6 (2016) announced the number of the countries suffering the urban water stress has grown from 36 to 41 in 13 years (United Nations, 2016). Meanwhile, epidemiological experts argue, due to reducing open space with urbanisation, the risk of residents' mental health problems is growing (Mechelli, 2019).All the issues are accompanied by changes in urban spatial density and pattern.

To face these challenges in urban sustainability, the researchers from different disciplines have been investigating many approaches. However, the issues are very complex: a new solution may easily initiate a new problem or a conflict. For example, to mimic the natural water cycle and reduce the stress on stormwater pipeline system, some green stormwater management facilities are popularly adopted and constructed in green space, such as bioretention swale, constructed wetland, etc. Although sometimes they bring extra aesthetic value to the green space, the residents cannot be allowed to access the space for activity anymore for protecting underground construction structure.

The Sustainable stormwater management measures mentioned above is one of the main research perspectives proposed to support sustainable urban development. The representatives are Low Impact Development (LID) from the USA (Stephen et al., 2010), Sustainable Urban Drainage Systems (SUDS) from the UK, Water Sensitive Urban Design (WSUD) from Australia (Myers, Pezzaniti, 2019), Sponge City (SC) from China (Nguyen et al., 2019) and so on. While they developed in different urban contexts with some specific characteristics, they share a common feature which is setting priority to utilise green space for detention and retention of stormwater onsite (Fletcher et al., 2015, Nguyen et al., 2019, Chan et al., 2018).

Green space is also a research domain for other researchers. Urban designers and epidemiologist have discussed the significance of the accessible and usable green space for human wellbeing for years (Ekkel, Vries, 2017, Christopher et al., n.d.). They explore to promote human wellbeing with green space, excluding any consideration of the stormwater management.

We should be aware that current sustainable stormwater management construction affect human wellbeing by dramatically reducing the accessibility and usability of green space for the public. The basic rule is the sustainable development of cities is not a near-perfect solution to the stormwater issue at the expense of other urban development needs.That's why Smart City

---

* Corresponding author

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
https://doi.org/10.5194/isprs-annals-VI-4-W2-2020-79-2020 | © Authors 2020. CC BY 4.0 License.

is proposed to integrate the information of various urban systems to make intelligent response to different kinds of needs, such as daily livehood and stormwater managment (Su et al., 2011, Neirotti et al., 2014).

To better use the limited urban green space resource serving human needs and protect the urban water environment, this research will endeavour to organize the spatial data related to stormwater management and human activity within one 3D parametric model. For the purpose, this paper reviews the design method and the main indicators of sustainable stormwater management and human wellbeing to identify the existing Potential defects and key data impacting on balancing the needs of sustainable stormwater management and human wellbeing.

The paper is organised as follows: (1) we review the main sustainable stormwater management measures with principles, models and facilities to reveal an overlooked but important relationship between space organization and stormwater management; (2) we review research on the relationship between green space and human to identify the importance of green space to human, as well as the key factor of green space for promoting human wellbeing; (3) we summarize the research characteristics of sustainable stormwater management and human wellbeing within space and identify the research gap and key data for effectively linking them within the same urban site. Then, this research will work towards associating sustainable stormwater management and promotion of human wellbeing within 3D parametric spatial model.

2. SUSTAINABLE STORMWATER MANAGEMENT

2.1 Main principles

Sustainable stormwater management has progressively developed worldwide. This concept is proposed as relative to traditional water management. It intends to restore and use green infrastructure to manage stormwater on-site, as well as to benefit the urban social, economic and ecological environment (Habtemariam et al., 2019, Herslund, Mguni, 2019, Qiao et al., 2020). To address the specific challenges from different urban context and climate conditions, some stormwater management concepts have been proposed. The main concepts include LID, WSUD and SC etc (Fletcher et al., 2015, Shen et al., 2019).

LID originates from USA is well-known around the world. It was launched to integrate site design and control measures to shape 'natural' hydrological system to manage stormwater runoff and water quality (Fletcher et al., 2015, Hayden et al., 2011). Just as Fletcher (2015) pointed out, LID is proposed by researchers to distinguish from the traditional 'large end-of-pipe detention systems'. It is mainly composed of on-site 'natural' treatment devices, such as bioretention swale, rain garden etc (Fletcher et al., 2015). As the location of these devices are on the green space near the source of stormwater runoff such as road, building etc., they are also quite close to residents.

WSUD is used in Australia to manage the urban water cycle aiming reducing negative impacts on hydrological environment. The core idea is mimicking natural hydrological system (Melbourne Water, 2013). By learning from natural water cycle, WSUD also adopts some green treatment devices, such as constructed wetland, raingarden etc, to soak, infiltrate and reuse the stormwater on-site. Considering the local specific water threaten (hydrological pollution, drought), WSUD highlights the importance of minimising water pollutant and supplement non-portable water source Melbourne and Sydney separately (Melbourne Water, 2013, Sydney Water, 2012).The common point is, like with LID, it operates on-site stormwater management through using green spaces that are intimately related to human settlements.

The 'natural' concept is also adapted by SC and practised in China (MOHURD, 2014, Nguyen et al., 2019, Chan et al., 2018, Wang et al., 2018b).As the development background of SC is the rapid and high-density developing country of China, researchers are exploring to set up a multi-scale design system starting from urban planning in order to organise the urban green space network to service stormwater management (Qiao et al., 2020, Shen et al., 2019). Based on the design system, they arrange different stormwater management devices to fit in different scales and satisfy the site needs (MOHURD, 2014). Within the high-density residential community, they also conducted SC renovation test with adopting the green stormwater management devices within limited green space to treat stormwater within the community. The devices include swale, tree box filter, rain garden, constructed wetland, detention pond etc (MOHURD, 2014).

As it can be seen, all three approaches intend to integrate green space within the water management system to keep down and infiltrate the stormwater on-site (Fletcher et al., 2015). Such measures effectively reduce the stress from unprecedented heavy rain on the traditional pipeline system with fixed conveyance capability. The basic approach for managing runoff is to use existing green space within the built environment as much as possible, and the rainfall is guided via the green space network rather into the pipeline system directly (Figure 1,2).

Compared to traditional water management which drains runoff quickly through pipes, sustainable water management mainly collects, filters, and reuses water via green spaces on site. Thus, sustainable water management has a great demand on urban green space. These green infrastructures work effectively for stormwater management by reducing the runoff speed, minimizing the volume of runoff and filtering the water pollutants. But the construction of these devices does not fully consider about human daily activities, even though their construction is close to the residents. This ignorance we can identify from their design models and adopted devices construction criteria.

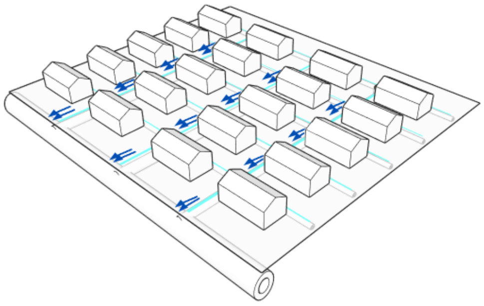

Figure 1. Conventional water management

2.2 Design models

Currently, the urban sustainable stormwater management projects are mainly guided by hydrological models. They include

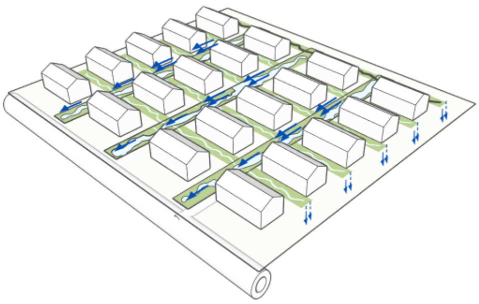

Figure 2. Sustainable Water Management

Storm Water Management Model (SWMM), MOdel for Urban SEwers (MOUSE), Model for Urban Stormwater Improvement Conceptualisation (MUSIC) and urban water modelling package(MIKE URBAN) etc. Although they are used in different urban context, their simulating process commonly focus the hydrological cycle to analyse runoff and carrying pollution (Huang et al., 2011, EPA, 2015, Guo et al., 2019, eWater, 2017). For example, SWMM divide the site as a collection of sub-catchments and simulates the runoff movement with nodes and lines (EPA, 2015). Although soil properties, rainfall volume and intensity are the main parameters used in the model, the site characteristics-such as width and slope of subcatchment etc.are included; The simulation result is in one dimension as shown in Figure 3 (EPA, 2015, Bisht et al., 2016). Even MIKE URBAN, as an upgraded SWMM model, just has 2D visual analysis simulating flood extent and flood inundation height (Bisht et al., 2016). Thus, without the visual space expression, these stormwater management models have limitations in testing the cross-influence between rainwater management and space, and integration with other disciplines.

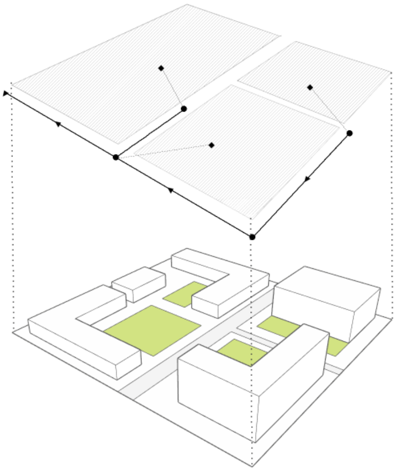

Figure 3. Schematic diagram of SWMM 1D output extracted from site space

2.3 Stormwater management Facilities

As mentioned above, the core idea of sustainable stormwater management is making full use of green space for stormwater detention, retention and infiltration on site instead of piping the stormwater directly off. Therefore, these facilities are always practiced in green space, and would have huge influence on the green space. We compare the different approaches looking at their characteristics listed for facilities constructed in green space. Applied region, space value, scale and shape of the facilities are the main points used for comparation and analysis.

The comparison has shown that these sustainable stormwater management measures have considered the relationship between stormwater management facilities and specific urban functions. To a certain extent, different urban functions have different scales and patterns of urban space (Christopher, 1977), which determines that the water management measures corresponding to them should also provide facilities with suitable spatial scales and shapes. For example, the shape of vegetated swale is a strip or landscape verge which is suitable to the linear urban space -street. In contrast, constructed wetlands require a large-scale area, so it cannot be arranged along linear roads, but needs to be combined with larger-scale urban function construction, such as urban parks. However, it is worth noting that, all the manuals list the suitable facilities targeting at urban functions rather than urban space pattern.

Facility	LID	WSUD	SC
Rain Garden	Driveways Low lying areas of a property	Streets	Low lying areas of a property
Vegetated Swale	Roads Drives Parking lots	Median strip Verge parks	Residential community Roads Parking lots
Infiltration Basins	Large scale land development	N/A	Large scale land development
Constructed Wetlands	N/A	Parks vacant land	Community urban green space Waterfront
Shallow Lakes	N/A	Aesthetic post wetland	Community urban green space Plaza

Table 1. Applied region of sustainable stormwater management facilities

Table 2 shows that the manuals have included the scale and shape of the stormwater management facilities in consideration in varying degree. They propose a certain size or a proportion with the catchment size to the specific facilities. It reflects the close relationship between the facilities and the space. But all the limitations on the scale and shape are set up based on the water engineering principles. For example, the size of vegetated swale is set as 5%-10% of catchment in the SC national guideline. It originates from the requirements on effectiveness of stormwater purification. Regarding the constructed wetland, it is commonly treated as the facility needs a substantial space to construct. All the manuals do not list the efficient use of urban space with integrating human needs or activities within the requirements. Thus, from urban design perspective, the relationship between the scale and shape of stormwater management facilities and the site space is non-existent, because it cannot reflect the surrounding needs and the interaction with human.

Facility	LID	WSUD	SC
Rain Garden	5-50m^2	Range of scales and shapes	N/A
Vegetated Swale	0.6-2.4m wide with 0.05-0.1m optimal water depth	N/A	Vegetated swale/catchment5% -10%
Infiltration Basins	Large trousands sq meter wet meadows	Require substantial area	Constructing on larger catchment ($\geq 1hm^2$)
Constructed Wetlands	Pocket wetlands to shallow marshes	Require large areas of land	N/A
Shallow Lakes	N/A	N/A	N/A

Table 2. Scale and shape of sustainable stormwater management

However, Table 3 shows that all the sustainable stormwater management measures have realised and confirmed the possibility of the additional value of the facilities. The challenge is this confirmation staying in the manual alone without any practical principles of spatial pattern or function arrangement.

Facility	LID	WSUD	SC
Rain Garden	No specify the space value in items	Landscape value	Easy to integrate with landscape
Vegetated Swale	„	Aesthetic appeal Habitat value	Easy to integrate with landscape
Infiltration Basins	„	Landscape value	N/A
Constructed Wetlands	„	Habitat visual Recreation amenity	Landscape Leisure entertainment
Shallow Lakes	„	Habitat visual Recreation amenity	N/A

Table 3. Space value of sustainable stormwater management facilities

Overall, although the sustainable stormwater management is more ambitious than the traditional stormwater management, just as Fletcher (2015) pointed out, the sustainable stormwater management is still primarily driven by the professionals from water engineering. It intends to reduce the dependence on pipeline networks with fixed excretion capacity rather bring the water detention and retention process back to ground green space on site to mimic the natural water cycle. As such, they believe it would not only minimize the stress on the fixed pipeline system but also make the urban environment more resilient. However, within the whole process, they ignored the needs of human wellbeing on the green space which is the critical to sustainable urban development as acknowledged in the SDGS (UN, 1992). Meanwhile it is difficult to integrate the factors of human wellbeing with the fixed 1D/2D hydrological model directly, so it is hard to intelligently manage the complex needs of dense settlemment developement. If we can establish a platform to connect the stormwater management and human wellbeing on the 'same page', it would make the stormwater management more sustainable and smarter.

3. RESEARCHES ON GREEN SPACE FOR HUMAN WELLBEING

3.1 Relationship between green space and human wellbeing

Human wellbeing in the built environment has been a hot research topic for some years (REF). With the rapid and high-density urbanization, protecting human wellbeing has become a huge challenge (Krefis et al., 2018, Thangavel, 2017).The relevant research investigations indicate that the factors impacting the human wellbeing are complex. The influence is not only from poverty and social factors (Atsuko et al., 1996, Ana V. Diez, 2002), but also the environmental changes, such as the reduction of green space (Tzoulas et al., 2007, Sjerp et al., 2003, Ekkel, Vries, 2017). The existing research investigations indicate a positive relationship between keeping urban green space and human wellbeing (Bertram, Rehdanz, 2015, Ekkel, Vries, 2017, Tzoulas et al., 2007). They explain the reason is green space have potential to contribute the human wellbeing, especially the mental health (Diana et al., 2010, Bertram, Rehdanz, 2015, James et al., 2015, Ekkel, Vries, 2017).

It is worth noting that the positive relationship between green space and human wellbeing is not simply decided by the scale of the green space. The existing studies mainly suggest that the mechanism of the positive relationship has two aspects. The first one has been generally accepted by public. Green space has specific aesthetic values which can address human attention fatigue (Stephen, 1995, Kaplan, 1989). The second one is the broadly discussed by researchers in recent years. They believe it is important that green space can provide an attractive venue for recreation, activities, exercises and social interaction (Pretty et al., 2007, Kaczynski, Henderson, 2007). By this way, the increasing outdoor activities can improve the personal social engagement, lower depression and keep health at certain levels (Diana et al., 2010, Pretty et al., 2007, Berger, Motl, 2000). The positive influence of green space on human wellbeing is plentiful.

3.2 Main metrics of positive relationship between green space and human wellbeing

To better understand the positive relationship between green space and human wellbeing, we will summarise the main metrics of green space listed in the relevant research as positive factors on human wellbeing. This summary is currently not based on a systematic literature review to reveal all the metrics of space impact on human wellbeing, such as an economic indicator. As the research target is to figure out the characteristics of space which impact the human wellbeing directly, this study exclusively focusses on the spatial metrics. It includes $proximity$, $accessibility$ and $usability$.

3.2.1 Proximity: Proximity is used to describe the distance from citizens' home to green space (Carter, Horwitz, 2014, Aggio et al., 2015). Just like mentioned before, the significance of living nearby green space to human wellbeing has been admitted in the 1990s (Stephen, 1995). But, in recent year, the researchers have kept investigation on the influence of distance to green space on human. Aggio (2015) discussed the importance of proximity to green space for children living style and health. Sturm (2014) argues that there is a close association between proximity to urban parks and human mental health by conducting survey (Sturm, Cohen, 2014). Researchers from Demark, Netherland and the UK also discussed the positive value of short distant green space to human wellbeing based on their local context (Stigsdotter et al., 2010, van den Berg et al., 2010, White et al., 2013). However, previous research does not provide substantial empirical evidence to prove the proximity of green space is positive to human health (Sturm, Cohen, 2014). Moreover, it can be found that proximity is not an independent factor. To some extent, it enhances the accessibility of the green space and encourage residents to enjoy more activities within the urban green space (Stigsdotter et al., 2010, van den Berg et al., 2010, Aggio et al., 2015, Carter, Horwitz, 2014).

3.2.2 Accessibility: Accessibility gives a different perspective as compared to proximity. It represents not only a short distance between green space and residents' home, but also indicates the green space is open to the public and provides places for free play (Ekkel, Vries, 2017, Carter, Horwitz, 2014). The investigation on accessibility represents the researchers have realised closer distance and big amount of green space do not equal to good quality green space for human wellbeing (van Dillen et al., 2012). Ekkel (2017) believes that accessibility is a comprehensive factor which is composed by size, distance and quality of green space. But sometimes accessibility is treated as a synonym for proximity. Comber (2008) and Coutts (2010) admitted that evaluating the accessibility of green space should consider the size and quality of green space. When they conducted the analysis with GIS data, the distance metrics still preform the main role (Comber et al., 2008, Coutts et al., 2010).

3.2.3 Usabilty: This metrics is used to provide a clearer requirement for green space from human wellbeing perspective.

Usability indicates that green space should be in close distance, open to the public as well as well-equipped for public activities, exercises and social meeting etc (Carter, Horwitz, 2014). Carter (2014) argues that usability of green space is more significant than accessibility because it emphasises the function of recreation which has a positive influence on human health. This viewpoint has been agreed upon by other researchers as well. The investigation conducted by Nutsford er al. (2013) shows that usability of green space has a positive association with decreased counts of anxiety, mood disorder treatments (Nutsford et al., 2013).Zhang et al. (2017) conducted a survey comparation between two neighbourhoods with different rates of usable green space. The survey result show that the neighbourhoods with higher usability of green space have higher satisfaction with living environment (Zhang et al., 2017).

Therefore, considering the current shortage of urban green spaces, to make a more effective contribution to the human wellbeing, green space design should consider usability and accessibility instead of purely pursuing the greenness and large scale (Ekkel, Vries, 2017).

3.3 Main methods to evaluate positive relationships between green space and human wellbeing

To promote the effectiveness of green space and contribute the human wellbeing, some research investigated the green space performance in order to guarantee humans get real benefits from green space as mentioned above. We have reviewed relevant research to summarise the main evaluation methods that have been adopted. The current research focusing on the relationship between green space and human wellbeing mainly rely on Survey investigation, GIS data analysis or mixed methods.

3.3.1 Survey: Survey is a quantitative and qualitative method which intends to collect as much as possible interests sampling and evaluate them with self-reports (Chiang et al., 2015). Chiang (2015) argue that “the only approach in psychology in which random sampling is routinely used”. Therefore, survey should be a very powerful method in human wellbeing. Zhang (2017) adopted survey method to identify the level of satisfaction of residents to different type of green space (more usable and less usable space) by collecting two group of samplings. Aggio (2015) conducted a longitudinal social survey on the lives of Scottish children from infancy through to their teens to understand the influence of distance to green space on children’s living style, especially TV time. Rehdanz (2015) employed a web survey method to investigate the park use patterns and the perception of green environment to analyse the role of green space in promoting human wellbeing (Bertram, Rehdanz, 2015).

Obviously, survey is effective to understand human needs, expectations and perceptions. Then, based on the collected survey data, one can conclude the main factors within the specific space closely associated with human wellbeing. But all this analysis is only human response-based, which means survey is used to reflect human subjective perception and need of space, rather than expressing the way of interaction between the specific spatial parameters and residents.

3.3.2 GIS data analysis: Comparing to survey, GIS data analysis is used to focus on space itself and therefore provides more objective results. This method relies on statistical analysis of spatial patterns and the underlying process with the integrated green space geographic data to prove some research assumptions or conclude an analysis result (Gimond, 2020). Comber (2008) adopted GIS data-based network analysis to evaluate the accessibility of green space. Kong (2007) built up a hedonic price model with amenity value of urban green space generated by GIS data analysis. The GIS-based spatial data is applied to generate a land-use map and calculate the “cost-distance” to evaluate the accessibility of green space (Kong et al., 2007). Zhang (2017) studied and categorised the usability of green space with amenities location of GIS database and site observation. Above all, GIS data analysis is a powerful method to analyse the performance of green space associated with human needs. It has been used to evaluate the key factors of the relationship between green space and human wellbeing—accessibility and usability. But current spatial analysis is mainly 2D, especially the distance calculation. Hence, some spatial characteristics impacting the usability of green space would be ignored. Furthermore, the current research on space for human wellbeing has also unawareness of the issue of stormwater management, just like stormwater management research has with human wellbeing. Therefore, current human wellbeing spatial research cannot smart organise the space of detailed useability for human activity, and handle the dense settlements environment without stormwater consideration.

4. INTEGRATING SUSTAINABLE STORMWATER MANAGEMENT AND HUMAN WELLBEING FOR URBAN SPACE

As mentioned above, it is an inevitable trend to develop sustainable stormwater management and promote human wellbeing in urban area to response in a smarter urban development way. But the question is how to avoid the conflicts on developing the limited urban green space between stormwater management and human wellbeing promotion. For example, if we only chase the stormwater management target to arrange the stormwater management device, which cannot allow residents access and use, in the central green space of the residential community, it would impact the human wellbeing a lot. Similarly, if we only consider the needs of people for space use for space organization and pavement of the site, it will also greatly affect the effectiveness and purification of rainwater collection within green space. Therefore this research proposes to extract the key spatial parameter related to human activity and stormwater managment and integrate them into spatial model to explore the smarter method organising green space.

4.1 Existing research on the integration of stormwater management and human wellbeing

Integrating stormwater management and human wellbeing within a model is not a brand-new research topic. One of the main challenges is that researchers are working with different platforms and data (Grose, 2014). To improve the spatial design performance, some researchers have tried to put the stormwater management in a design platform.

Wang (2018) developed a browser-based cooperation platform to enhance the collaboration between stormwater management and humanized spatial design (WANG et al., 2018a). Their workflow is running SWMM model in the background after inputting relevant site data, such as soil, precipitation, elevation data etc. Then based on the output of SWMM model simulation, the program will set different landscape spatial module to fit in the certain size of space (WANG et al., 2018a). Therefore, Wang’s (2018) research principle is still rooted in hydrological theory. However, the expectation of human wellbeing on green space haven't been thoroughly considered within the model. Meanwhile, it divides the whole workflow into two steps and operates in a different model environment, so it still cannot really combine stormwater management together.

Compared to Wang's research, Chen (2016) developed a parametric spatial model to integrate LID requirements within a 3D spatial analysis environment. Its principle is simulating the stormwater collection process within the 3D model to estimate the runoff volume of architecture and green space (Chen et al., 2016). Then by visualising the runoff process, it can support designers to create adaptive stormwater management measures to fit in site condition (Chen et al., 2016). Although this research also weakened the human daily needs during the simulation process, it already brought the stormwater simulation into a 3D space environment, rather than still relying on the 1D hydrological model. It provides the possibility of balancing stormwater management and human need at a same spatial model.

4.2 Niche of parametric spatial model

The core of balancing the needs of stormwater management and human wellbeing proportion is to understand and coordinate the way they use green space. Thus, the challenge is to bring both on the same page and understand their dynamic relationship. This means we should find a platform be 'friendly' for both of them and also simulate the dynamic process of stormwater and human daily movement.

Parametric model can, based on computer, treat different spatial attributes as variables to simulate certain space system (Schumacher, 2015). As the variable can be dependent to reflect the value change of another relevant variable of the model (Barrios, 2005), it can be an open platform to organize the analysis of the human needs and sustainable stormwater management together within green space via setting specific spatial variables. Therefore, the key point is identifying the exact attributes of space impacting on the space performance on stormwater management and human activity.

Space can be 'presented by multiple disciplines as a notion referencing our living environment' (Zlatanova et al., 2020). For example, the dense and height of trees will impact the accessibility of green space (Wang et al., 2020). And the spatial slope is one key factor affecting water flow speed. Actually, parametric spatial analysis has been developed for decades, and categorize the space into different characteristics elements: isovists, convex spaces and axial line (Martin et al., 2012, Chen, Wenwen, 2017). Thus We can reference the existing spatial model and test to organize the spatial metrics (size, distance, elevation etc.) to negotiate the balance of human interests and stormwater management needs (Figure 4).

It should be noted that the human behaviour and stormwater changes are dynamic. The parametric spatial environment provided by Grasshopper can simulate the whole process of runoff movement on the ground with impact on site, and human movement as well. With the space category support, we can simplify the complex 3D space environment to set up the research framework with a sort of stock(space) and flow in 3D model. For example, through the identification of boundary parameters in the spatial model, it is analysed whether there is an interactive relationship between the space used by people and the functional green space, so as to classify the positive and negative spaces (Figure 5).

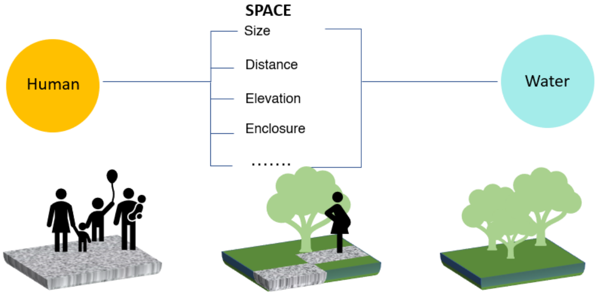

Figure 4. Schematic diagram of the balance between water management and human wellbeing

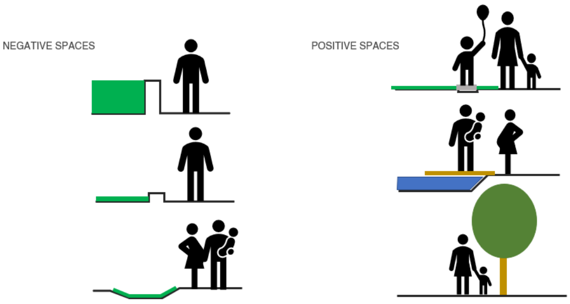

Figure 5. Schematic diagram of spatial classification

Lastly, the parametric spatial platform provided by Grasshopper can visualise the analysis output and design result in real-time. Therefore, it can integrate the spatial analysis, design and simulation within a same system which can reduce the waste of time for transferring between different work platform (Figure 6).

5. CONCLUSION

This paper presented a literature review and the motivation for a parametric 3D spatial model to develop a smarter sustainable stormwater management by integrating human space needs. As space is a limited resource in urban development, how to intelligent use of limited space resources is the core of this article. The potential advantage of the proposed parametric 3D spatial model is it can transfer the requirements and limitation on space from different disciplines into the certain spatial metrics by referencing their theories. However, we cannot deny that the urban environment is too complex to entirely be reflected within a parametric model, the model can be used to support the early stage of design and provide the reference for more comprehensive design model development.

REFERENCES

Aggio, D., Smith, L., Fisher, A., Hamer, M., 2015. Mothers' perceived proximity to green space is associated with TV viewing time in children: the Growing Up in Scotland study. *Preventive medicine*, 70, 46–49.

Ana V. Diez, R., 2002. Invited Commentary: Places, People, and Health. *American Journal of Epidemiology*, 155(6).

Atsuko, T., Takehito, T., Keiko, N., Sachiko, T., 1996. Health Levels Influenced by Urban Residential Conditions in a Megacity—Tokyo. *Urban studies*, 33(6).

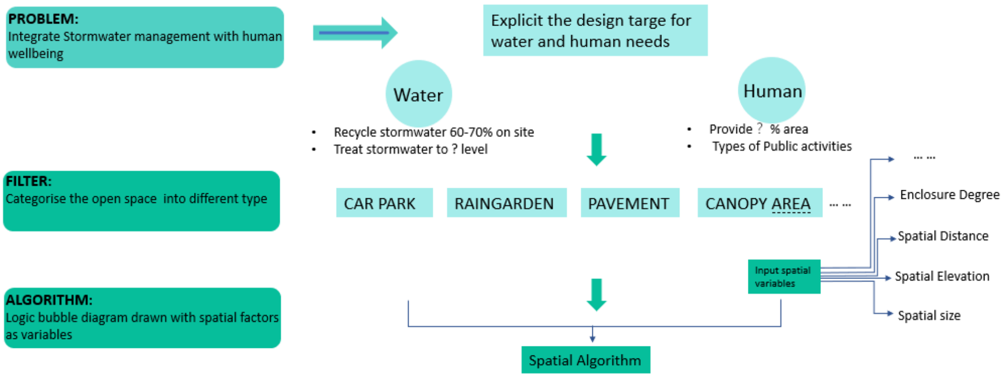

Figure 6. Schematic diagram of entire workflow of integrating stormwater and human wellbeing within one parametric model

Barrios, C., 2005. Transformations on parametric design models. *Computer Aided Architectural Design Futures 2005*, Springer, 393–400.

Berger, B. G., Motl, R. W., 2000. Exercise and mood: A selective review and synthesis of research employing the profile of mood states.

Bertram, C., Rehdanz, K., 2015. The role of urban green space for human well-being. *Ecological Economics*, 120, 139–152.

Bisht, D. S., Chatterjee, C., Kalakoti, S., Upadhyay, P., Sahoo, M., Panda, A., 2016. Modeling urban floods and drainage using SWMM and MIKE URBAN: a case study. *Natural Hazards*, 84(2), 749–776.

Carter, M., Horwitz, P., 2014. Beyond proximity: the importance of green space useability to self-reported health. *EcoHealth*, 11(3), 322–332.

Chan, F. K., Griffiths, J. A., Higgitt, D., Xu, S., Zhu, F., Tang, Y.-T., Xu, Y., Thorne, C. R., 2018. “Sponge City” in China—A breakthrough of planning and flood risk management in the urban context. *Land Use Policy*, 76, 772–778.

Chen, F., Wenwen, Z. (eds), 2017. Grasshopper Reach Analysis Toolkit: Interactive Parametric Syntactic Analysis.

Chen, Y., Samuelson, H. W., Tong, Z., 2016. Integrated design workflow and a new tool for urban rainwater management. *Journal of environmental management*, 180, 45–51.

Chiang, I.-C. A., Rajiv S. Jhangiani, Paul C. Price, 2015. *Overview of Survey Research*. BCcampus.

Christopher, A., 1977. *A Pattern Language: Towns, Buildings, Construction*. Oxford university press, Berkeley, California.

Christopher, I., Cathy, O., Benjamin, C., Ascelin, G., Sarah, B., n.d. Planning for green open space in urbanising landscapes.

Comber, A., Brunsdon, C., Green, E., 2008. Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. *Landscape and Urban Planning*, 86(1), 103–114.

Coutts, C., Horner, M., Chapin, T., 2010. Using geographical information system to model the effecs of green space accessibility on mortality in Florida. *Geocarto International*, 25(6), 471–484.

Diana, E. B., Lisette, M. B.-A., Teri, M. K., Andrew, S. P., 2010. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health*.

Ekkel, E. D., Vries, S. d., 2017. Nearby green space and human health: Evaluating accessibility metrics. *Landscape and Urban Planning*, 157, 214–220.

EPA, U., 2015. Storm water management model user’s manual version 5.1. www.epa.gov.

eWater, 2017. MUSIC overview. https://ewater.org.au/products/music/music-overview/.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., Viklander, M., 2015. SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7), 525–542.

Gimond, M., 2020. Intro to gis and spatial analysis. mgimond.github.io.com.

Grose, M. J., 2014. Gaps and futures in working between ecology and design for constructed ecologies. *Landscape and Urban Planning*, 132, 69–78.

Guo, X., Du, P., Zhao, D., Li, M., 2019. Modelling low impact development in watersheds using the storm water management model. *Urban Water Journal*, 16(2), 146–155.

Habtemariam, L. W., Herslund, L. B., Mguni, P., 2019. What makes a champion for landscape-based storm water management in Addis Ababa? *Sustainable Cities and Society*, 46, 101378.

Hayden, E., Mark, L., Jane, P. (eds), 2011. LOW IMPACT DESIGN MANUAL FOR THE AUCKLAND REGION: CHALLENGES AND SOLUTIONS TO IMPLEMENTING LID.

Herslund, L., Mguni, P., 2019. Examining urban water management practices – Challenges and possibilities for transitions to sustainable urban water management in Sub-Saharan cities. *Sustainable Cities and Society*, 48, 101573.

Huang, G., Huang, J., Yu, H., Yang, S., 2011. Secondary Development of Storm Water Management Model SWMM Based GIS. *Water Resource and Power*, 04.

Ignacio, O., Matthew, M., Priyanie, A., 2018. Fighting floods with ’sponge cities’. *Bangkok Post*. https://www.bangkokpost.com/opinion/opinion/1406334/fighting-floods-with-sponge-cities.

James, P., Banay, R. F., Hart, J. E., Laden, F., 2015. A Review of the Health Benefits of Greenness. *Current epidemiology reports*, 2(2), 131–142.

Kaczynski, A. T., Henderson, K. A., 2007. Environmental Correlates of Physical Activity: A Review of Evidence about Parks and Recreation. *Leisure Sciences*, 29(4), 315–354.

Kaplan, R., 1989. *The experience of nature : a psychological perspective*. Cambridge University Press, Cambridge and New York.

Kimmelman, M., 2017. Rising Waters Threaten China’s Rising Cities. *The New York Times*. https://www.nytimes.com/interactive/2017/04/07/world/asia/climate-change-china.html.

Kong, F., Yin, H., Nakagoshi, N., 2007. Using GIS and landscape metrics in the hedonic price modeling of the amenity value of urban green space: A case study in Jinan City, China. *Landscape and Urban Planning*, 79(3-4), 240–252.

Krefis, A., Augustin, M., Schlünzen, K., Oßenbrügge, J., Augustin, J., 2018. How Does the Urban Environment Affect Health and Well-Being? A Systematic Review. *Urban Science*, 2(1), 21.

Li, X., Li, J., Fang, X., Gong, Y., Wang, W., 2016. Case studies of the sponge city program in china. C. S. Pathak, D. Reinhart (eds), *World Environmental and Water Resources Congress 2016*, American Society of Civil Engineers, Reston, Virginia, 295–308.

Martin, B., Sven, S., Reinhard, K., 2012. Parametric Urban Patterns: Exploring and integrating graph-based spatial properties in parametric urban modelling. *Design Tool Development*, 1(eCAADe 30).

McGranahan, G., Balk, D., Anderson, B., 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization*, 19(1), 17–37.

Mechelli, A., 2019. Cities increase your risk of depression, anxiety and psychosis – but bring mental health benefits too. theconversation.com (20 May 2020).

Melbourne Water, 2013. South-Eastern-councils-WSUD-guidelines. https://www.tandfonline.com.

MOHURD (ed.), 2014. *Technical Guideline for Sponge City: The Construction of Low Impact Developed Storm Water System*.

Myers, B. R., Pezzaniti, D., 2019. Flood and peak flow management using wsud systems. *Approaches to Water Sensitive Urban Design*, Elsevier, 119–138.

Neirotti, P., de Marco, A., Cagliano, A. C., Mangano, G., Scorrano, F., 2014. Current trends in Smart City initiatives: Some stylised facts. *Cities*, 38, 25–36.

Nguyen, T. T., Ngo, H. H., Guo, W., Wang, X. C., Ren, N., Li, G., Ding, J., Liang, H., 2019. Implementation of a specific urban water management - Sponge City. *The Science of the total environment*, 652, 147–162.

Nutsford, D., Pearson, A. L., Kingham, S., 2013. An ecological study investigating the association between access to urban green space and mental health. *Public health*, 127(11), 1005–1011.

Pretty, J., Peacock, J., Hine, R., Sellens, M., South, N., Griffin, M., 2007. Green exercise in the UK countryside: Effects on health and psychological well-being, and implications for policy and planning. *Journal of Environmental Planning and Management*, 50(2), 211–231.

Qiao, X.-J., Liao, K.-H., Randrup, T. B., 2020. Sustainable stormwater management: A qualitative case study of the Sponge Cities initiative in China. *Sustainable Cities and Society*, 53, 101963.

Schumacher, P., 2015. Design parameters to parametric design. *The Routledge Companion for Architecture Design and Practice: Established and Emerging Trends*, 3–20.

Shen, J., Du, S., Huang, Q., Yin, J., Zhang, M., Wen, J., Gao, J., 2019. Mapping the city-scale supply and demand of ecosystem flood regulation services—A case study in Shanghai. *Ecological Indicators*, 106, 105544.

Sjerp, d. V., Robert, A. V., Peter, P. G., Peter, S., 2003. Natural Environments—Healthy Environments? An Exploratory Analysis of the Relationship between Greenspace and Health. *Environment and Planning*, 35.

Stephen, K., 1995. The restorative benefits of nature: toward an integrative framework. *Journal of environmental psychology*, 15.

Stephen, L., Steven, L. A., Cory, A. A., Katie, B. e. a., 2010. *Low Impact Development: A Design Manual for Urban Areas*. University of Arkansas Press.

Stigsdotter, U. K., Ekholm, O., Schipperijn, J., Toftager, M., Kamper-Jørgensen, F., Randrup, T. B., 2010. Health promoting outdoor environments–associations between green space, and health, health-related quality of life and stress based on a Danish national representative survey. *Scandinavian journal of public health*, 38(4), 411–417.

Sturm, R., Cohen, D., 2014. Proximity to Urban Parks and Mental Health. *The journal of mental health policy and economics*, 17(1), 19–24.

Su, K., Li, J., Fu, H., 2011. Smart city and the applications. *International Conference on Electronics, Communications and Control (ICECC), 2011*, IEEE, Piscataway, NJ, 1028–1031.

Sydney Water, 2012. The history of sydney water. www.sydneywater.com.au (2012).

Thangavel, P., 2017. *Rapid urbanisation: opportunities and challenges to improve the well-being of societies — human development reports: United nations development programme*. hdr.undp.org.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and Urban Planning*, 81(3), 167–178.

UN, 1992. Rio Declaration on Environment and Development. A/CONF.151/26 (Vol. I).

United Nations, 2016. Goal 6 : Sustainable development knowledge platform: Ensure availability and sustainable management of water and sanitation for all. sustainabledevelopment.un.org (20 May 2020).

University of Oxford, 2019. Rapid urbanization increasing pressure on rural water supplies globally. sciencedaily.com (20 May 2020).

van den Berg, A. E., Maas, J., Verheij, R. A., Groenewegen, P. P., 2010. Green space as a buffer between stressful life events and health. *Social science & medicine (1982)*, 70(8), 1203–1210.

van Dillen, S. M. E., de Vries, S., Groenewegen, P. P., Spreeuwenberg, P., 2012. Greenspace in urban neighbourhoods and residents' health: adding quality to quantity. *Journal of epidemiology and community health*, 66(6), e8.

WANG, H., Liu, H., Guo, Y., 2018a. Primary Exploration of Interactive and Cooperation Platform between Landscape Architecture and Stormwater Management. *Rain and Flood Management*.

Wang, H., Mei, C., Liu, J., Shao, W., 2018b. A new strategy for integrated urban water management in China: Sponge city. *Science China Technological Sciences*, 61(3), 317–329.

Wang, Y., Cheng, Y., Zlatanova, S., Palazzo, E., 2020. Identification of physical and visual enclosure of landscape space units with the help of point clouds. *Spatial Cognition & Computation*, 1–23.

White, M. P., Alcock, I., Wheeler, B. W., Depledge, M. H., 2013. Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. *Psychological science*, 24(6), 920–928.

Xu, N., 2012. Beijing floods: not enough prevention. *The Guardian*. https://www.theguardian.com/environment/2012/jul/25/flooding-china.

Zhang, Y., van den Berg, A. E., van Dijk, T., Weitkamp, G., 2017. Quality over Quantity: Contribution of Urban Green Space to Neighborhood Satisfaction. *International journal of environmental research and public health*, 14(5).

Zlatanova, S., Yan, J., Wang, Y., Diakité, A., Isikdag, U., Sithole, G., Barton, J., 2020. Spaces in Spatial Science and Urban Applications—State of the Art Review. *ISPRS International Journal of Geo-Information*, 9(1), 58.

Revised January 2020