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T.M. Leung, I.V. Kukina, A.Y. Lipovka
Siberian Federal University, Russian Federation, Krasnoyarsk, Svobodnypr. 79
e-mail: jer.jerry@gmail.com, ikukina@inbox.ru, alex.lipovka@gmail.com

A PARAMETRIC DESIGN FRAMEWORK FOR A SPATIAL STRUCTURE OF OPEN SPACE DESIGN IN EARLY DESIGN STAGES

Abstract: *The notion of a parametric urban design has become a phenomenon recently. Researchers have been searching for various parameters related to urban morphology. Tremendous efforts have also been put into investigating how parametric modelling could be adapted for designs in both large and small scale urban plans. In parallel, there has been an increased concern on the issue of urban sustainability. Specifically, numerous studies attempted to deal with human comfort in urban spaces, which can be categorized as social sustainability. As performance evaluation should be an essential part of parametric modelling, it will be natural to ask how environmental performances that affect human comfort directly can be incorporated into a parametric urban design process. However, previous studies concerning parametric urban design and environmental performances in terms of human comfort have been mainly focused on searching for optimized designs. Even worse, most of these studies have been primarily about the environmental performances of the final design solutions. Since human comfort should not be the only criterion in urban design, it is of importance to generate design options that can yield similar comfort levels for further design explorations. This is especially important at an early sketch design stage since a lot of decisions in this stage will restrict the environmental performances of the final design solutions. However, designers usually do not consider this issue at the beginning of the design process as there is no proper tool to incorporate human comfort in early design stages. As a result, the primary objective of this study is to layout a parametric urban design framework which can generate design options according to the desired comfort levels at a sketch design stage. Green open spaces that are considered to be basic elements of urban fabric, and thermal comfort constituted by trees in these spaces will be adapted to demonstrate how the design framework can guide the development of a parametric model for generating design options.*

Keywords: *parametric design, green open space, thermal comfort, early design stage.*

Introduction

The notion of a parametric urban design has been actively investigated recently. There have been studies that have been focused on identifying the parameters to be included in parametric urban design models (Beirão & Duarte, 2009). It has also been demonstrated in previous studies that parametric models could be utilized to generate urban design solutions in both big and small scales (Koltsova et al., 2011, 2012). On the other hand, there have been studies focusing on how parametric models can aid the decision-making process of a design task. Parametric urban design models could also help designers to easily understand how design solutions would affect urban morphology, especially the issue of urban density. A parametric model has been developed so that the urban indicators such as Ground Space Index (GSI) and Open Space Ratio (OSR) could be calculated in real time when the urban design option is generated (Beirao et al., 2011). With a parametric urban design model, a design process could begin with dynamic information such as traffic and demographic information (Tang & Anderson, 2011) so that the dynamic dimensions of urban systems could be dealt with. Meanwhile, parametric models could help to analyze sophisticated morphological data that could not be easily processed with traditional design methods (Feng & Zhang, 2009).

Due to the increased awareness in sustainability, more studies have been devoted to explore designs that are ecological friendly. To this end, there have also been researchers who attempted to improve the environmental performance of urban design solutions by using parametric design models. In UAE, for example, it has been demonstrated that solar irradiation and wind speed of urban developments could be optimized by the use of parametric urban design models (Taleb & Musleh, 2015). Parametric urban design models have been also adapted to plan the distribution of green spaces in cities (Yazıcı, 2016). Although it has been shown from these studies that it is possible to use parametric urban design models to improve or optimize the environmental performances of design solutions, most of the studies have been mainly focused on the later stages of design only. Environmental performances are usually simulated after the design is generated. In fact, performances have not been usually not considered in early stages of the a design process, no matter parametric urban design models have been utilized or not. It has been suggested that designers would usually neglect the performance of the design in early design stages (Koltsova et al., 2012). One of the reasons might be that environmental performance simulation is usually a time-consuming process. Special computer tools will be needed to perform the simulations.

In the realm of digital design, however, it has been suggested that performance evaluation of the design could be a part of the brainstorming process (Singh & Gu, 2012). The notion of performance-based digital design model also suggested that designers should be able to interact with the performance during the digital design process (Oxman, 2006). As a result, it would be of interest to investigate how environmental performances can be included as a part of parametric urban design models which can support early stages of the design process.

Consequently, this study is aimed at developing a design framework to guide the development of parametric urban design models which embraces environmental performances as model inputs. The models developed under this framework that aids early stages of the design process, should be able to generate design options by inputting the desired performance levels. The application of the design framework would be demonstrated by a case study for an open space design.

Methodology

According to Oxman (Oxman, 2006), a performance-based digital design model should allow designers to interact with the digital representation, generation process, performance and evaluation process of the design. Basically, the model framework developed in this study followed this concept. However, the evaluation process has not beenconsidered in this study because the framework would be used to develop parametric urban design models to generate design options in early design stage. Further design exploration would be needed after these options were generated. Fig. 1 shows the main concept behind the model development framework adapted in this study.

Parametric Model Development

In this study, the main idea is to demonstrate how parametric model embracing environmental performances as the input could be developed. Mathematically, this model could be expressed as:

$$DO = F(P, X) \tag{1}$$

where *DO* is a design option generated by the parametric model; *P* is a set of environmental performances considered in the model; *X* is a set of parameters included in the model.

Usually, only the parameters are included as inputs in a parametric design model. However, both the environmental performances and parameters would be included as inputs of the model in this study. The steps to develop such a model will be demonstrated in the following case study.

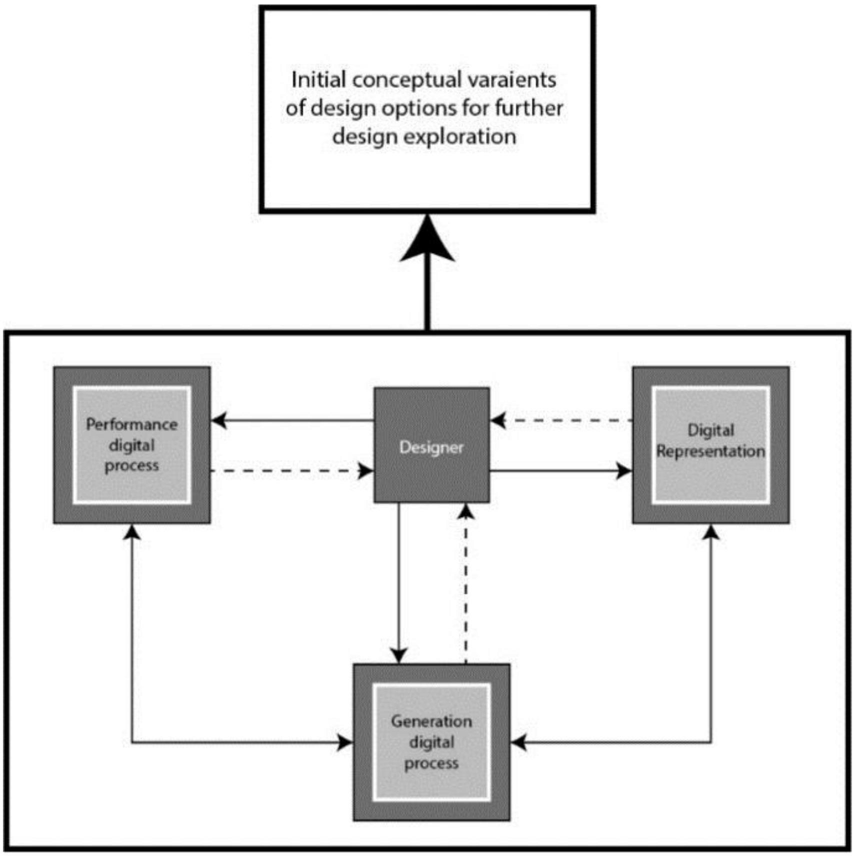


Figure 1. Concept behind the model framework (modified from (Oxman, 2006))

Case Study

A virtual site in the shape of a square was defined for the case study. It was assumed that the site was situated in Hong Kong. The dimensions of it were assumed to be 50m x 50m. The site was an open space with three sides enclosed by buildings while the entrance to it was at the south. It was also assumed that the designer could make a decision on the height of the buildings as long as they were of the same height. Trees would be planted in the open space at least 3m from the edges of it. Fig. 2 shows the configuration of the site.

Meanwhile, it would be necessary to select an appropriate tool for the development of the parametric model. Grasshopper of Rhino3D has been chosen as the tool to develop the model. It has been widely used in previous studies concerning parametric urban designs (J. Beirão et al., 2012; Suyoto et al., 2015). The visual interface of Grasshopper makes it one of the best options to create parametric design models. Ladybug, which is a Grasshopper add-on, has been used in the case study to quantify thermal comfort in the open space.

Four main steps will be involved when developing a parametric urban design model with both environmental performances and parameters as inputs. First, the performance goals have to be defined. Second, parameters related to the design will be identified. Relationship between the environmental performances and some of the parameters will then be developed. Finally, the performances, parameters, and the relationship between them will be put together to form the parametric model.

Define the Performance Goals

Since the model to be developed will include environmental performances as a part of inputs, it will be essential to define the performance goals first . In this case study, the performance to be investigated in the model will be thermal comfort in the open space. In fact, factors such as shading effects and wind speed can affect thermal comfort in open spaces. Shading effects provided by the trees and building surrounding the site will be considered in this case study.

Besides, it is also a must to quantify the performance levels. It will not be possible to include the performance in concern into the parametric model if the performance levels are not quantified. In this case study, it is the thermal comfort level that has to be quantified. To this end, Universal Thermal Climate Index (UTCI) has been adapted as an indicator for thermal comfort level. UTCI has been adapted in a number of previous studies concerning outdoor thermal comfort (e.g. Lai et al., 2014). The change in comfort level in relation to shading effects provided by tree planting and various building heights will be quantified by the change in average UTCI (in degree Celsius) in the space. In terms of the weather data, the hottest week of the year in Hong Kong, that is determined as 22 July to 28 July, has been considered. Average wind speed and humidity of this week will be used for UTCI estimation.

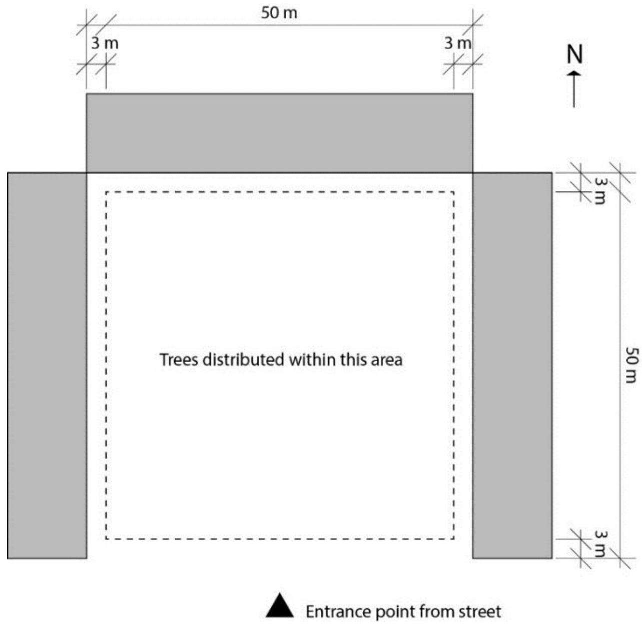


Figure 2. Configurations of the virtual site

Identify the Parameters

Identifying the parameters should be considered as a standard procedure when developing a parametric model. In fact, it will be impossible to virtually include all the parameters related to the design task into the model. For the sake of demonstration, only parameters related to the performance goal being considered have been included in the case study. Specifically, a tree size and shape, and building heights are the parameters included in the model in this case study. A random function has been used for the tree distribution. It should be noted that the number of trees in the open space has not been included as a parameter because the model calculates the number of trees after the desired reduction in UTCI is defined. The values of a tree size and shape have been fixed in the case study. The height of tree has been fixed at 4.5m while the tree crown diameter is 4 m. Besides, all the trees are of a round shape.

Relationships between Performances and Parameters

In order to make performance goals as inputs of a parametric urban design model it is needed to identify mathematical relationships between the environmental performances and parameters. There can be two different scenarios when these relationships are considered. If these relationships have already been developed previously, adapting these relationships will be preferred. On the contrary, it will be necessary to develop the relationships between the performances and parameters if these relationships have not been developed before. In the current case study, no relationship between the reduction in UTCI and the parameters in concern has been developed before. As a result, the relationship has to be developed. The Grasshopper add-on

Ladybug has been used to estimate the average UTCI in the open space. Due to various tree distributions, the average UTCI might vary even when the number of tree has been the same. As mentioned, the trees in the open spaces have been distributed by utilizing a random function. The average UTCI has been estimated for 5 times (i.e. 5 different random tree distribution scenarios) for the same number of trees with different building heights. Fig. 3 shows the relationship between the reduction in UTCI and the number of tree with various building heights.

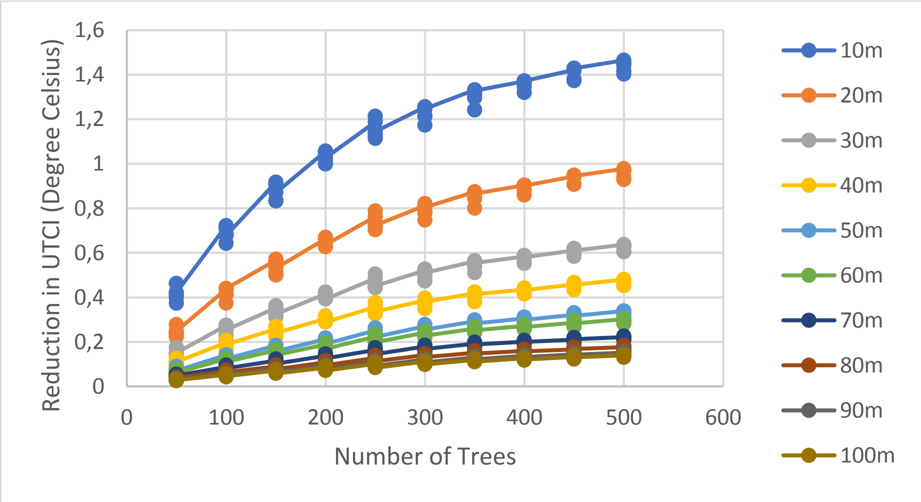


Figure 3. Relationship between the reduction in UTCI and the number of trees with various building heights

It can be seen from Fig. 3 that the reduction in UTCI basically has increased with the number of trees. When the building height is equal to or above 50 m, the relationships between UTCI reduction and tree number ae very close to a linear one. When the building height is 50 m, average UTCI reduction has been found to be 0.33°C even if the number of trees is 500. With this tree number, the average UTCI reduction has been even lower (0.14°C) when the building height is 100 m. As the effect on UTCI reduction due to shading effects of tree planting has been considered to be low when a building height has been equal to or higher than 50 m, the range of a building height in the model is between 10 m and 40 m. Since a building height affected the range of UTCI reductiongreatly, the input range of UTCI reduction in the parametric model will be set according to the values defined for building heights. Table 1 shows the parameters and performance inputs of the parametric model.

Meanwhile, the relationships between the reduction in UTCI and the number of trees with different building heights have been obtained by a regression analysis. A total of four statistical models that correspond to the four different building heights, have been formed.

$$UTCI\ Reduction = 0.461 ln(Tree\ Number) - 1.412 \quad (2)$$

$$UTCI\ Reduction = 0.323 ln(Tree\ Number) - 1.052 \quad (3)$$

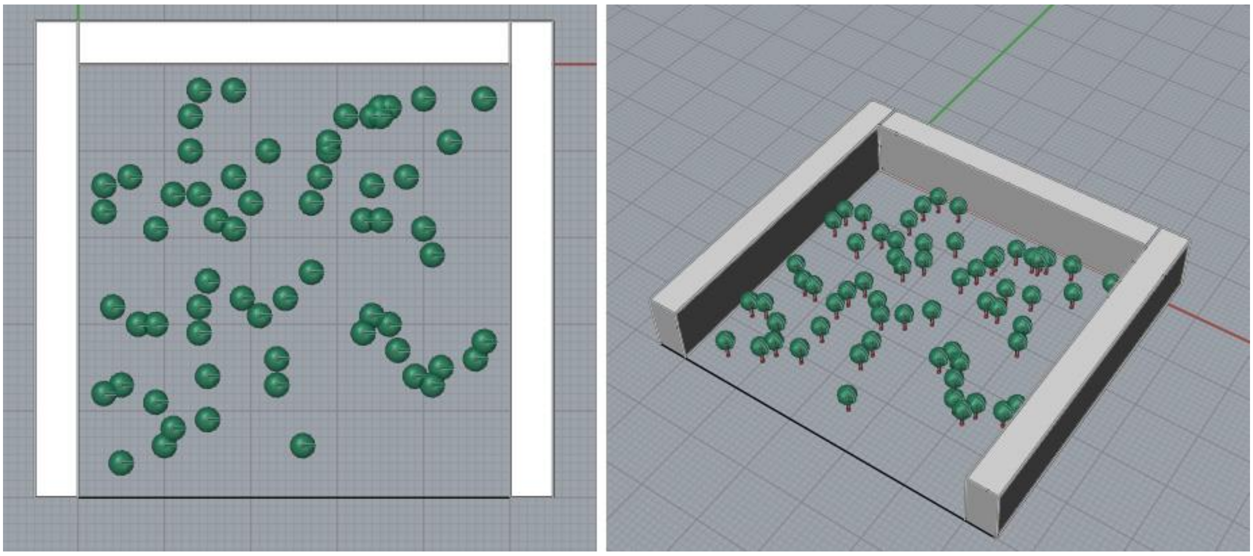
$$UTCI\ Reduction = 0.214 ln(Tree\ Number) - 0.714 \quad (4)$$

$$UTCI\ Reduction = 0.162 ln(Tree\ Number) - 0.546 \quad (5)$$

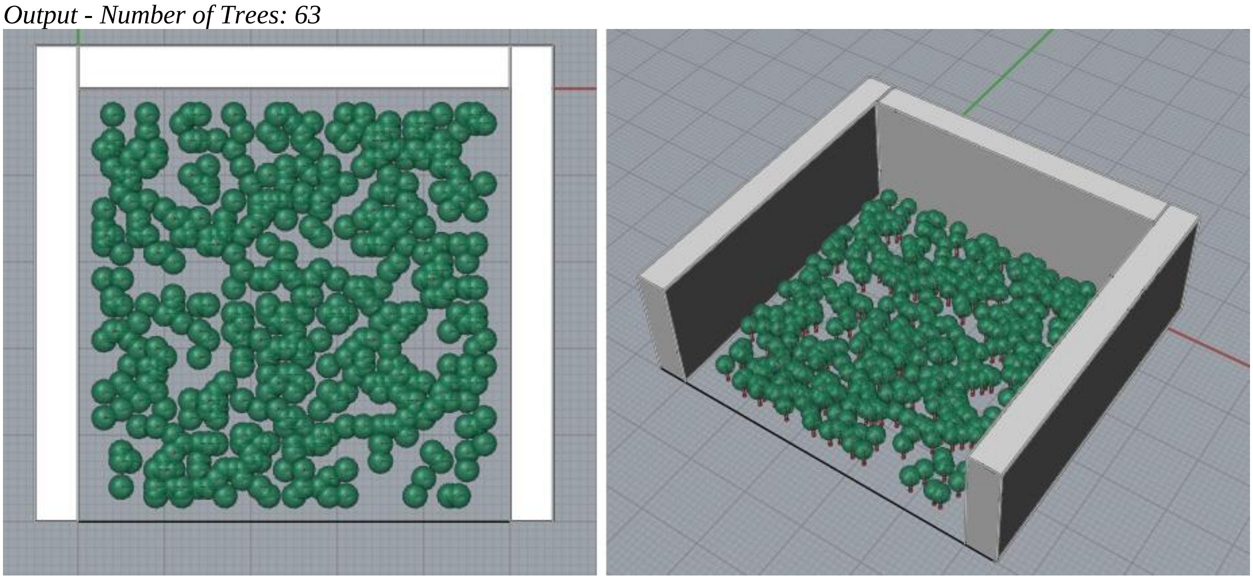
Here, equations (2) to (5) have been the statistical models formed when building heights have been 10, 20, 30 and 40 m respectively. The adjusted R^2 of them have been found to be 0.99, 0.99,0.98 and 0.98 which means that equations (2) to (5) are very accurate in order to obtain the number of trees with different UTCI reductions.

Forming the Parametric Model

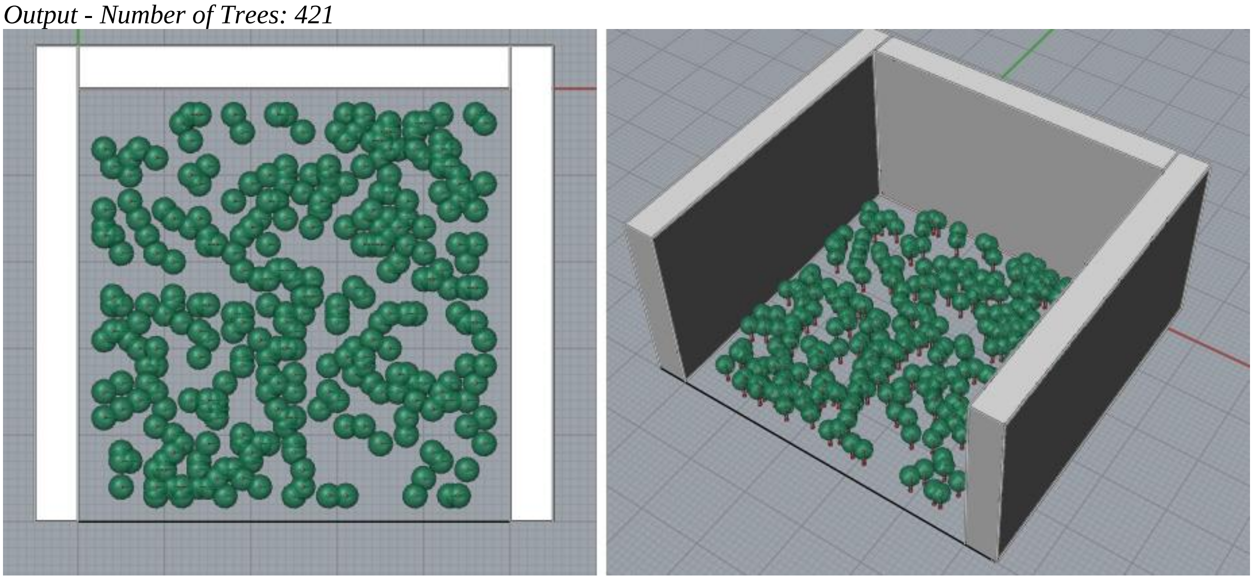
With the performance and parameter inputs, as well as equations (2) to (5), a parametric urban design model with performances as inputs could be formed. Figure 4 shows examples of design options generated by the model.



Input - Building Height: 10 m; UTCI Reduction: 0.5^{o}C
Output - Number of Trees: 63



Input - Building Height: 20 m; UTCI Reduction: 0.9^{o}C
Output - Number of Trees: 421



Input - Building Height: 30 m; UTCI Reduction: 0.5^{o}C
Output - Number of Trees: 291

Figure 4. Examples of design options generated by the parametric model

Table

Parameters and performance inputs of the parametric model

Inputs	Description
Performance	
Reduction in UTCI	0.42 to 1.45°C (a building height = 10 m) To 0.11 to 0.47°C (a building height = 40 m)
Parameters	
Tree Height	4.5 m
Tree crown diameters	4 m
Tree shape	Round
Building Height	10, 20, 30 and 40 m

Conclusions and Discussions

Traditionally, performances are considered as n output of a design. Performances of a design will not be simulated until later stages of the design task. One of the reasons is that special software packages and techniques are needed in order to simulate the performances (e.g. thermal performance) of a design option. With the use of a parametric urban design model, however, it will be feasible to partly reverse the process. Including performances as inputs has becpome possible. In this study, a design framework to develop such a parametric model has been formulated. The feasibility of developing such a model has been demonstrated in the case study.

When developing a parametric model with performances as parts of inputs, formulating mathematical relationship between the performances and parameters is considered an extremely crucial step. As seen in the case study, building heights can influence the average UTCI in the open space greatly. Although this is obvious, it is not be possible to determine the exact ranges of the parameter building height and the UTCI reduction before the average UTCI with various combinations of parameters are estimated. It has been found that tree shading for thermal comfort might not be needed when building height is equal to or greater than 50 m. It is not possible to determine the ranges of values of both the performance levels and parameters without the formulating the mathematical relationships between performancesand parameters.

In this case study, building height has been defined as a parameter. In reality, a building height might not be a parameter due to design brief or plot ratio requirements. In the case that the building height (or other parameters related to the performances considered) is fixed, it is needed to investigate if it is necessary to include the performances in the model. If the building height is fixed at 100 m in the case study, it is not necessary to include thermal comfort in the model. Other types of performances should be considered in the model instead. This notion should also be true when applying this model framework to other urban design tasks.

Thermal comfort in the open space has been included as an input in the parametric design model developed in the case study. In fact, open space is always considered one of the basic elements in cities. Thermal comfort has been one of the major factors that affect open space usage. It has been also suggested that individuals tend to utilize the shaded areas in open spaces (Bruse, 2007). Extending the case study from a virtual site to real sites help to design open spaces that can attract more people.

The model framework can also be applied to design tasks in larger scales. In this case, urban indicators such as Ground Space Index (GSI) and Open Space Ratio (OSR) can be included as performance inputs in the parametric urban design model. To this end, the model will be able to help generate open space distribution options in relation to the density of a given area. With this model, it will be possible to connect urban morphology with thermal performances when generating urban design solutions.

Meanwhile, it should be noted that the parametric model framework developed is not meant to optimize the performance of a design. The process of design optimization may still be needed in later stages of the design task. In fact, the inclusion of performances as input in the parametric model is based on simplified relationship between the performances and parameters. This is also why this model framework is more suitable for an early design stage. The parametric model developed under the model framework should never be considered as a substitution of performance simulation when the design is nearly completed. A detailed performance simulation is still needed in later stage of the design task.

References

1. Beirão, J., Arrobas, P., & Duarte, J. (2012). Parametric Urban Design: Joining morphology and urban indicators in a single interactive model. In *Proceedings of the 30th International Conference on Education and research in Computer Aided Architectural Design in Europe (eCAADe)*. Prague: ECAADe.
2. Beirão, J. N., & Duarte, J. P. (2009). Urban design with patterns and shape rules. In E. Stolk & M. te Brömmelstroet (Eds.), *Model Town: Using Urban Simulation in New Town Planning*. Amsterdam: SUN.
3. Beirao, J. N., Nourian Ghadi Kolaee, P., & Mashhoodi, B. (2011). Parametric urban design: An interactive sketching system for shaping neighborhoods. In *Proceedings of the 29th conference on education and research in computer aided architectural design in Europe (eCAADe)*. Ljubljana: eCAADe, Faculty of Architecture, University of Ljubljana.
4. Bruse, M. (2007). Simulating human thermal comfort and resulting usage patterns of urban open spaces with a Multi-Agent System. In *Proceedings of the 24th International Conference on Passive and Low Energy Architecture (PLEA)*.
5. Feng, H., & Zhang, Y. (2009). Computational urbanism - A parametric relational urban model model for urban plot ratio allocation. In *The Proceedings of the 4th International Conference of the International Forum on Urbanism (IFoU)*. Amsterdam.
6. Koltsova, A., Schmitt, G., Schumacher, P., Sudo, T., Narang, S., & Chen, L. (2011). A Case Study of Script-Based Techniques in Urban Planning. In *Design Computing and Cognition '10* (681–700). Dordrecht: Springer Netherlands.
7. Koltsova, A., Tuncer, B., Georgakopoulou, S., & Schmitt, G. (2012). Parametric Tools for Conceptual Design Support at the Pedestrian Urban Scale. In *Proceedings of the 30th International Conference on Education and research in Computer Aided Architectural Design in Europe (eCAADe)* (279–287). Prague: ECAADe.
8. Lai, D., Guo, D., Hou, Y., Lin, C., & Chen, Q. (2014). Studies of outdoor thermal comfort in northern China. *Building and Environment*, *77*, 110–118.
9. Oxman, R. (2006). Theory and design in the first digital age. *Design Studies*, *27*(3), 229–265.
10. Singh, V., & Gu, N. (2012). Towards an integrated generative design framework. *Design Studies*, *33*(2), 185–207.
11. Suyoto, W., Indraprastha, A., & Purbo, H. W. (2015). Parametric Approach as a Tool for Decision-making in Planning and Design Process. Case study: Office Tower in Kebayoran Lama. *Procedia - Social and Behavioral Sciences*, *184*, 328–337.
12. Taleb, H., & Musleh, M. A. (2015). Applying urban parametric design optimisation processes to a hot climate: Case study of the UAE. *Sustainable Cities and Society*, *14*, 236–53.
13. Tang, M., & Anderson, J. (2011). Information Urbanism: Parametric urbanism in junction with GIS data processing & fabrication. In *Proceedings of ARCC Conference 2011*. Detroit.
14. Yazıcı, S. (2016). A parametric landscape urbanism method: The search for an optimal solution. *A/Z : ITU Journal of Faculty of Architecture*, *13*(3), 155–165.