Inclusion of Soundscape in Parametric Urban Design Model: a Case Study

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Abstract: Acoustic environment in open spaces is one of the issues that must be considered when designing cities. Besides the properties of sound sources, previous studies have suggested both urban morphology and building typology would affect soundscape in urban spaces. Sizes and shapes of urban spaces could have effects on the sound levels inside the spaces. On the other hand, acoustic environment in urban spaces was found to be related to height and façade design of buildings. Consequently, it is important to craft urban spaces with care in terms of the acoustic environment. On the other hand, there has been a recent trend to perform urban design tasks with the use of parametric urban design models. It has been demonstrated that parametric urban design can be applied to design tasks in different urban scales. There have also been studies which combined the notion of environmental performances with parametric urban design. However, few attempts have been made to include soundscape in parametric urban design models. As a result, the primary objective of the current study was to explore how soundscape could be included in a parametric urban design model. The feasibility of including soundscape as a parameter input in the model would be investigated. An experiment for open space design would be utilized to demonstrate the procedures to develop such a parametric urban design model.

1. Introduction

Open spaces are an important part of cities. They will help define the structure of the urban fabric. To this end, tremendous efforts have been put to improve the design of open spaces. Due to the increase in awareness of environmental sustainability nowadays, it is not uncommon for designers to consider environmental aspects of open space designs. To this end, there has been a special interest in improving the acoustic performance of open spaces.

Usually, the acoustic performance of an open space is regarded as the quality of the acoustic environment of the space. The acoustic performance would be considered preferable if users of the open space do not feel acoustically annoyed. The idea of soundscape, which means "*an acoustical composition that results from the voluntary or involuntary overlap of different sounds of physical or biological origin*" (Farina, 2014) could be employed to understand the acoustic performance of an open space. This means that both the types and acoustic properties such as the sound pressure levels of the sounds in the open space would be considered simultaneously.

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Previous studies showed that morphology could affect the acoustic environement in open spaces (Guedes *et al.*, 2011). Building topology such as facade design would also play a role in the acoustic environment in cities (Picaut *et al.*, 2006). On the other hand, natural sounds could improve the acoustic performance of open spaces. Specifically, users of open spaces would usually prefer the acoustic environment more when water sound (Jeon *et al.*, 2012) was introduced. Besides, studies suggested that a sound masking effect could be brought by water sound in urban spaces. The introduction of water sound could render the noise annoyance brought by traffic noise lower (Jeon *et al.*, 2010). The perceived loudness of traffic noise could be reduced by the introduction of water sound in open spaces (Coensel *et al.*, 2011). Meanwhile, there were also studies focusing on the masking effect of different types of water sound (Rådsten-Ekman *et al.*, 2013; You *et al.*, 2010). Fountain sound, which is one of the most common water sounds in open spaces, could provide such type of masking effect (Axelsson *et al.*, 2014; Galbrun & Ali, 2013).

In parallel, the notion of parametric urban design has become a phenomenon recently. Efforts have been devoted by both researchers and practitioners in order to understand various possibilities of parametric urban design. The notion of parametric urban design has been employed in studies in urban space design in various scales. (Koltsova *et al.*, 2011, 2012). There were studies focusing on understanding the algorithm (Schneider *et al.*, 2011) and parameters (Beirão & Duarte, 2009) of parametric urban design models. There were also studies which attempted to include the environmental performance of the design in the parametric urban design model. A study in UAE showed that thermal comfort of urban space could be optimized by using parametric urban design models (Taleb & Musleh, 2015). In another study, the notion of solar envelope was adapted in the parametric design model so as to ensure solar access in urban spaces (Saleh & Al-Hagla, 2012). On the other hand, efforts have been devoted to understanding how open space design can be done by utilizing parametric urban design (Leung *et al.*, 2017).

Despite the efforts in examining the feasibility of parametric urban design and acoustic performance of open spaces, most of these studies only considered thermal performance. The feasibility of including other types of environmental performances in the parametric design models was rarely investigated. Specifically, few studies have considered the notion of parametric design together with acoustic performance for open space design. Even worse, how the idea of soundscape can be employed in parametric design for open spaces was still unknown. It would be of interest to consider soundscape or acoustic performance a driving force for parametric design for open spaces. Accordingly, the primary objective of this study is to investigate the feasibility to include soundscape as a parameter input in a parametric design model for open space design.

2. Method

2.1. *Mathematical Concept*

In the current study, soundscape or acoustic performance would be treated as an input to the parametric urban design model. Mathematically, a design option *DO* could be generated by considering the following formula:

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

where *P* is the acoustic performance; *X* is a set of physical parameters included in the model.

Usually, the variable *P*, which is the acoustic performance of the design, would not be included as an input of a parametric urban design model. It would be considered an output of the model. This means that designers would only be informed about the acoustic performance after the design has been generated. By using equation (1), it would be possible to consider soundscape as an input of the model. Designs of open spaces could be generated by defining the required acoustic performance in this case.

2.2. *Virtual site*

A design experiment was conducted in order to understand how soundscape could be included in a parametric design model for open space design. To this end, a virtual site was defined in the current study. As the main focus of the current study is acoustic performance of open spaces, it was not necessary to define the climate zone in which the site was located. The geographic location of the site would not affect the acoustic performance of the design. Meanwhile, it was assumed that the site was in rectangular shape. Both the length and width of the site were alterable (from 50 m to 200 m). Three sides of the site were enclosed by buildings while one side of it was facing a trunk road. The trunk road was set to be 2 m from the edge of the site. The height of the buildings was set to be 17.5 m (5 storey buildings). One fountain in a circular shape would be located in the site. The diameter of the fountain was assumed to be 20 m. The location of the center of fountain was assumed to be at least 20 m away from the site edge. The sound pressure level of fountain sound was 65 dBA at the edge of the fountain. Besides, the sound pressure level induced by traffic noise at the entrance point of the site was 70 dBA. Figure 1 and Table 1 show the configurations of the virtual site defined in the current study and the details of the parameters employed.

2.3. *Design scenarios*

Before developing the parametric design model, it was needed to generate design scenarios and reveal the acoustic performance of them. Design scenarios were generated by changing the alterable parameters shown in Table 1 step by step. The width and length of the site increased from 50 m to 200 m, in a step of 10 m. Meanwhile, the fountain position has to be defined

Table 1. *Parameters employed in the current study.*

Parameters		Description
Alterable	Site Width	50m to 200m
	Site Length	50m to 200m
	Fountain Position	Center of fountain was not closer than 20 m from the edge of site
Unalterable	Fountain Diameter	20 m (The fountain was assumed to be of a circular shape)
	Water Sound Level	65 dbA at the edge of the fountain
	Traffic Noise Level	70 dbA at the entrance of the site

mathematically so as to generate the design scenarios. The location of the center of fountain was defined by using a 2-dimensional coordinate system. Figure 2 illustrates how the location of the center was defined. The *x* and *y* coordinates of the center of fountain were set to increase in a step of 5 m. The design scenarios were generated by using Grasshopper, which is a Rhino 3D plugin for parametric design.

In order to build the parametric design model, it was needed to quantify the acoustic performance of the model. The notion of soundscape was employed. Both the types of sound (fountain sound and traffic noise) and acoustic properties the sounds (sound pressure levels) should be considered in the parametric design model. In a previous study conducted by Leung *et al.* (Leung *et al.*, 2017), it was found that this probability was affected by fountain sound level, traffic noise level, as well as the difference between these sound pressure levels. A statistical relationship connecting this probability and the sound pressure levels of fountain sound and traffic noise was formulated in this previous study. By using this relationsihp, it was possible to estimate the probability of having low noise annoyance level in the site. In the current study, this relationship was adapted and the acoustic performance of the site was defined as the average probability of having low noise annoyance level in the site.

For each of the design scenario, a 5 m x 5 m grid system was imposed in the site. Pachyderm, a sound simulation add-on for Grasshopper, was used to estimate the sound pressure levels of the fountain sound and traffic noise at each point of the grid. On the other hand, the formula for estimating the probability of having low annoyance was scripted into Grasshopper and this probability at each point on the grid could in turn be found. The average probability was the mean of the probability values at these points in each design scenario.

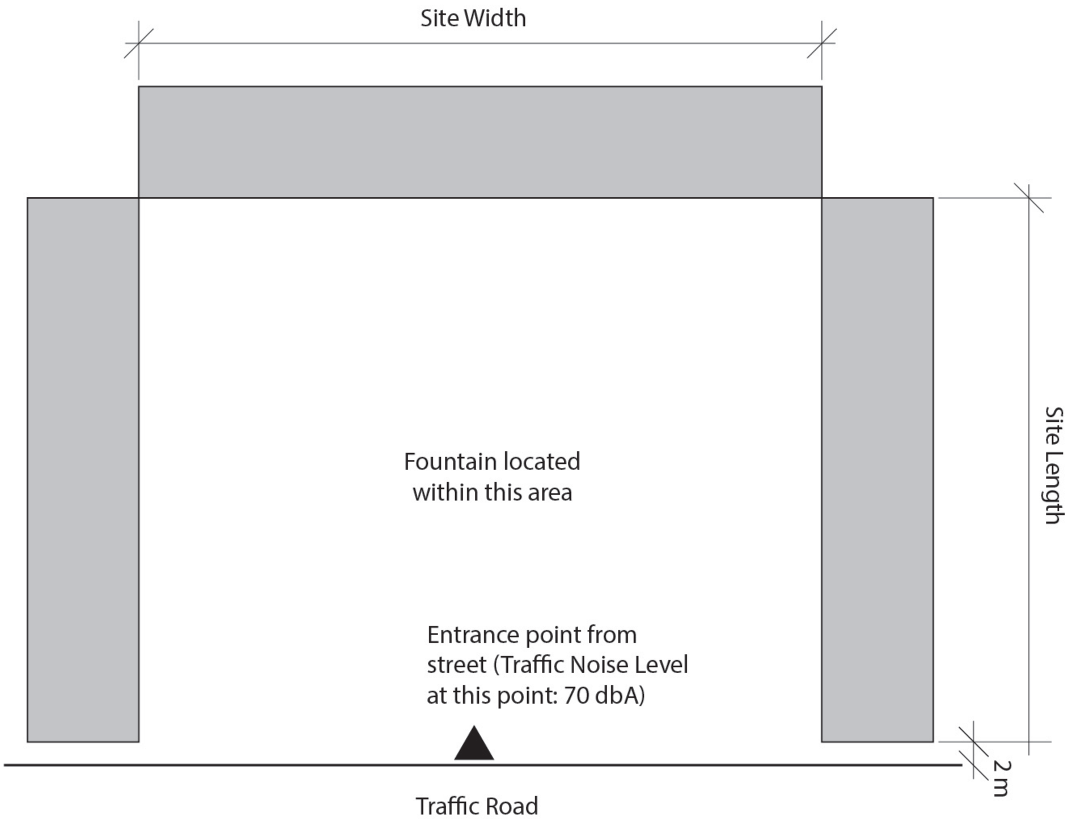

Figure 1. *Configurations of the virtual site.*

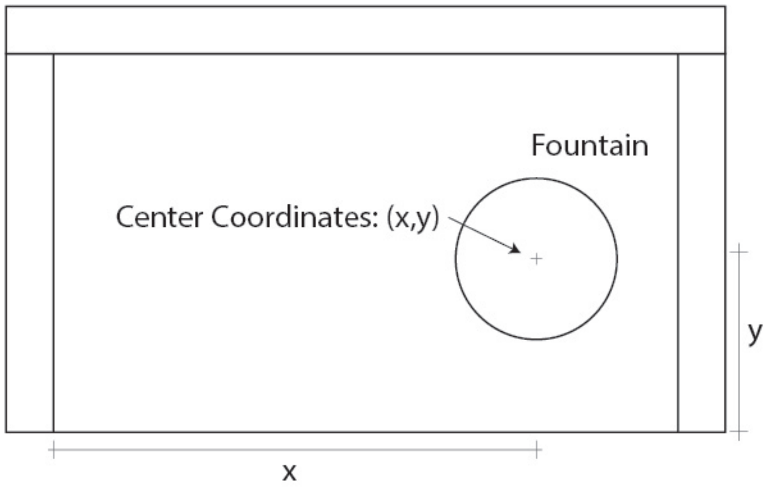

Figure 2. *Defining the location of fountain.*

2.4. *Parametric design model development*

With the average probability of each scenario, the relationship between the average probability of having low noise annoyance level and site configurations would be revealed. This relationship would be programmed into Grasshopper so that design of the open space can be generated by a given average probability value. Both 2-D and 3-D graphical representations of the design could be generated by using the parametric design model.

3. Results

Figures 3 and 4 show the estimation of the probability of having low annoyance level in Grasshopper and an example of the graphical representation of the sound pressure levels generated by Pachyderm. After the average probability of having low annoyance of each design scenario was estimated, correlation analysis was performed. It was found that the ratio of *x*-coordinate of the center of fountain to the site width and the *y*-coordinate of the center of fountain to the site length were correlated to the average probability. Table 2 shows the results of correlation analysis.

Meanwhile, it was also hypothesized that the site area would affect the average probability of having low noise annoyance level. Together with the variables shown in Table 2, the following mathematical relationship was proposed:

$$Pr = \beta_0 + \beta_1 SiteArea + \beta_2 \frac{xcor}{SiteW} + \beta_3 \frac{ycor}{SiteL}$$

where *Pr* is the average probability of having low noise annoyance; *xcor* and *ycor* are the *x* and *y* coordinates of the center of the fountain; β_0 is the constant term; β_1 to β_3 are the coefficients of the independent variables.

Linear regression technique was employed to reveal the relationship between average probability of having low noise annoyance level and the independent variables shown in equation (2). The adjusted R^2 was estimated to be 0.927. This suggested that equation (2) should be valid to reveal the average probability of having low noise annoyance in the site. Table 3 shows the regression results.

By using the regression results, it would be possible to find the dimensions of the site and the position of the fountain given a target average probability of having low noise annoyance in the site.

Grasshopper was utilized to develop the parametric design model. The main reason for this choice was that components developed for design scenario generation could be reused in the parametric model. Using a tool different from the one used for scenario generation would render it difficult to reuse the components. Meanwhile, designers would be required to input the target probability of having low noise annoyance, as well as some of the physical parameters related to the design of the open space. For example, a design could be generated when the target probability of having low annoyance, site width and length, *x*-coordinate of the center of the fountain were defined. The *y*-coordinate of the center of fountain could be determined by the model in this case. Figure 5 and 6 show the Grasshopper environment of the parametric model and two example design outputs from the model.

4. Conclusion and discussions

In the current study, a parametric design model which included acoustic performance as an input for open space design was successfully developed. Usually, performances of a design would only be estimated after a design option has been generated. This is considered a "synthesis – test" process. The model developed in the current study, however, adapted a reserved approach. The target acoustic performance of the open space design could be defined by the designer and the design would be generated by the parametric urban design model. This idea was inline with the

Table 2. *Correlation between probability of having low annoyance and parameters.*

	Ratio of x-coordinate of fountain center to site width	Ratio of y-coordinate of fountain center to site length
Average probability of having low noise annoyance	-0.465**	0.404**

*** significant at 0.01 level*

Table 3. *Regression analysis results.*

Parameters	Coefficient	Standardized Coefficient	Significance
Site Area	0.00000451**	0.760**	<0.001
Ratio of x-coordinate of fountain center to site width	-0.063**	-0.230**	<0.001
Ratio of y-coordinate of fountain center to site length	0.064**	0.194**	<0.001
(Constant)	0.537**	-	<0.001

***significant at 0.01 level*

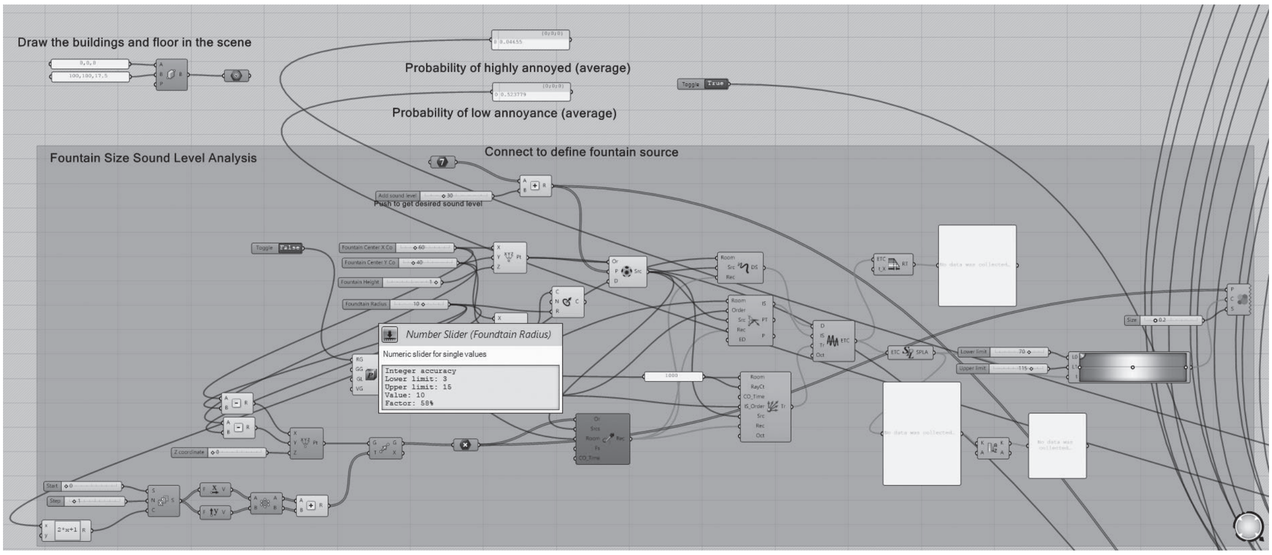

Figure 3. *Estimation of the probability of having low noise annoyance in Grasshopper.*

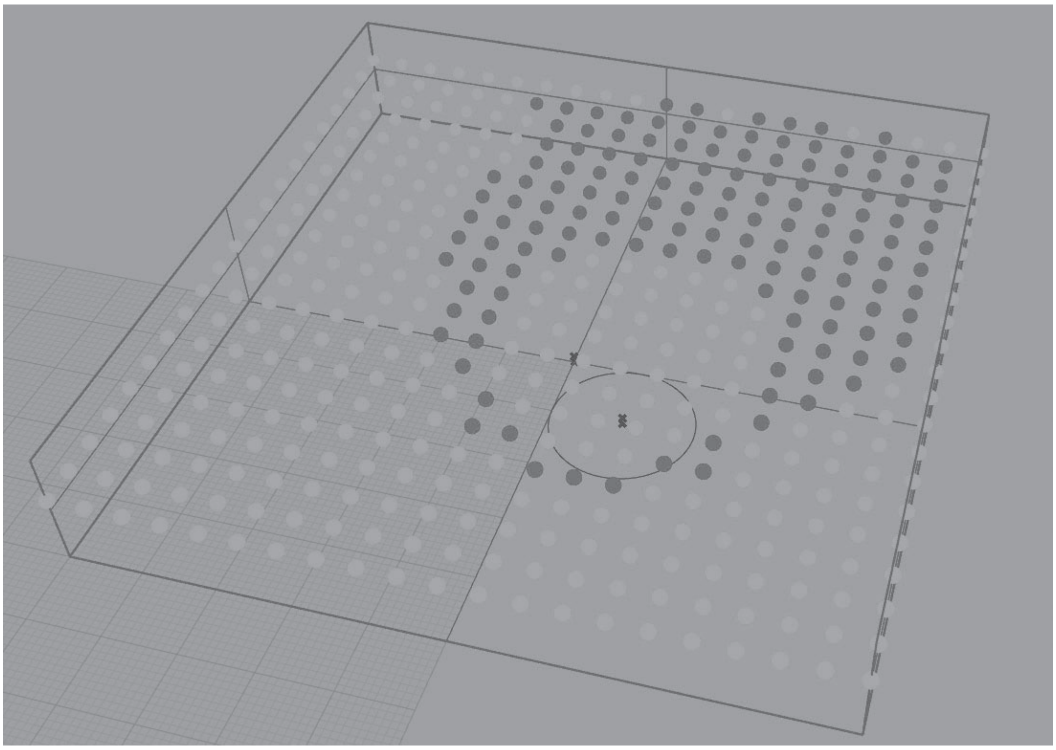

Figure 4. *An Example of graphical representation generated by using Pachyderm.*

notion of performative parametric urban design, which means that the performance of the design would be considered the driving force of the model to generate design solutions.

As a pilot study about including acoustic performance as an input in a parametric design model for open space design, only the location of fountain and dimensions of the site were alterable in the model developed in the current study. To make the model more flexible, it would be desirable to make more parameters alterable. As a result, the next step of the current study would be attempting to make the number of fountains, sizes of the fountains, as well as the

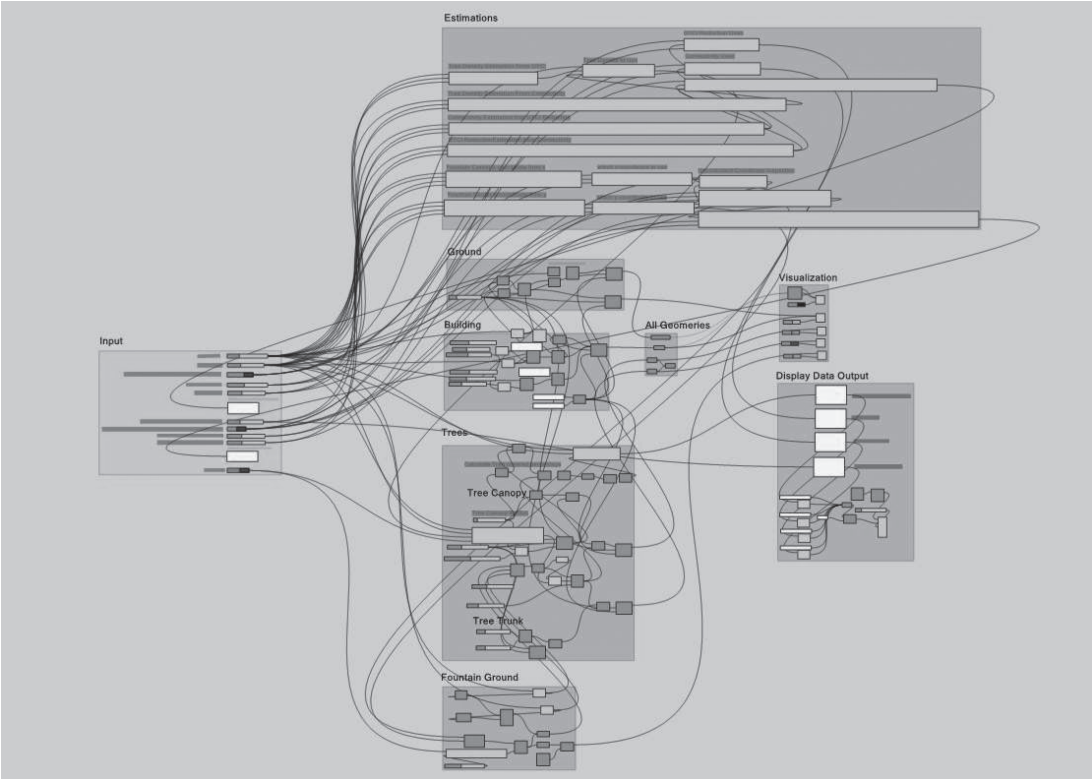

Figure 5. *Grasshopper interface of the parametric design model.*

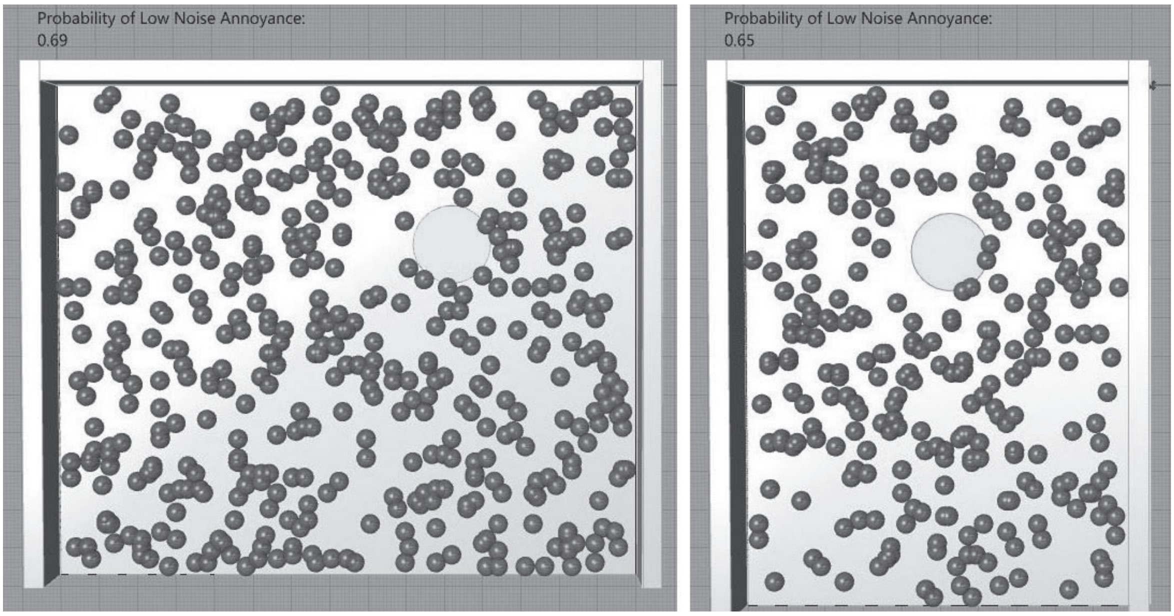

Figure 6. *Example design outputs of the parametric design model.*

sound pressure levels of fountain sounds alterable so that the model could become more flexible in terms of design solution generation.

Soundscape approach was employed in the current study. In fact, acoustic performance of an open space should be more than merely sound levels. Utilization of soundscape approach would help to ensure a more holistic consideration about the acoustic performance when generating the design solution. However, only water sound and traffic noise were considered in the current study. It is expected that other types of sound in open spaces will be included in further studies. For example, human noise, which is one of the most common noise sources in open spaces, will be included in further studies.

Only acoustic performance was considered in the current study. To develope a comprehensive parametric design model for open spaces, it would be needed to include more types of performances in the model. In fact, this is a part of a larger study which aimed at investigating how multiple performances of the design could be included as inputs in a parametric urban design model. In this larger study, thermal performance, acoustic performance, as well as spatial structure of open spaces were included as input in the parametric design model. It is expected that this larger study would help to add an extra layer of understanding for the performative approach of parametric urban design.

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