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**Effects of vegetation on soundscape of an urban religious precinct: Case study of
Myeong-dong Cathedral in Seoul**

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ABSTRACT

This study investigates the effect of vegetation for noise reduction and the changes in the soundscape of an access road to a religious space in Seoul. The noise propagation was investigated by performing field measurements before vegetation covered with soil, one month after, and four years after vegetation, and the overall soundscape perception was studied by conducting a social survey. The vegetation was added to the access road of the Myeong-dong Catholic Cathedral precinct, which is responsible for religious and social functions. As the vegetation became established, the sound pressure level tended to be reduced more, with particularly significant decreases in the 1 kHz and higher bands. Furthermore, before vegetation covered with soil and immediately after vegetation, the reverberation time varied between 1 and 2 s; however, as the planted trees grew and their leaf canopies became thicker, the reverberation time was reduced to 1.2 s or less. Consequently, the speech transmission index was improved four years after vegetation. The survey results showed that the participant perceptions of the overall quality and acoustic quality increased at statistically significant levels, but the increase in the perceived visual quality was not statistically significant.

Keywords: Urban space, Vegetation, Noise reduction, Soundscape, Reverberation, Social survey

1. Introduction

As sustainability is becoming increasingly important in modern urban planning, the introduction of vegetation in so-called “green areas” is become more common in urban spaces. Urban green spaces are beneficial for the environment; improve visual satisfaction; and can prevent damage due to flood or drought, purify air, and assist with various species-specific conservation efforts [1–5]. Vegetation in urban spaces where multiple sounds are reflected can have particularly positive effects on the soundscape in terms of reverberation time (RT) and noise attenuation. Therefore, various vegetation types and planting locations should be investigated to develop the best methodology for improving the urban soundscape. Various resources have been applied to develop urban green spaces [6,7]. In particular, introducing vegetation on building roofs has been suggested as an effective means of improving energy efficiency [8–12] and enhancing the sound environments of residential housing areas, which frequently suffer from noise problems associated with urban spaces [13–16].

The acoustic effects of vegetation in urban areas have been investigated through a detailed study called the international project HOSANNA (HOListic and Sustainable Abatement of Noise by optimized combinations of Natural and Artificial means), which was conducted mostly by European countries [17,18]. The main objectives of this project included identifying sustainable methods of reducing urban noise using vegetation, developing traffic noise reduction strategies, recommending standards for evaluating the sound effects of mitigation strategies, and verifying such strategies through laboratory or in-situ tests and forecasting models that can be applied to noise maps [17,18]. Recent studies have also suggested enhancing the sound environments in urban spaces by adding noise-reducing vegetation to building walls or roofs [14,19–21].

In addition to the acoustic effects of vegetation, many studies have shown that the visual aspects of vegetation significantly affect soundscape perception [22–25]. For instance, the visibility of outdoor vegetation has been shown to reduce noise annoyance [25–27], and vegetated environmental noise barriers can enhance the perceived noise barrier performance [23]. In addition, vegetation can enhance the overall perception of the urban environment [17,18,22,24,28]. However, very few studies have been performed to investigate the acoustic and perceptual effects of vegetation in practical landscape designs [29,30], and such research is essential to validate the feasibility of vegetation components as soundscape design elements.

In this context, the present study investigated the effects of vegetation on the noise reduction and soundscape changes along an access road to the Myeong-dong Cathedral precinct in Seoul, which is shown in Fig. 1.

Fig. 1. Myeong-dong Cathedral Precinct.

The Catholic cathedral precinct is the area of the cathedral, which is centered along the route connecting the cathedral square and the front gate of the cathedral beyond the secular space [31]. This space has complex spatiality, which is derived from historical, cultural, and religious developmental processes. The inside of the cathedral, which usually rises into the sky, was arranged to direct the flow of people toward the central altar. The religious space of the cathedral starts from the main gate with its spire and is limited to inside the cathedral. In other words, the external space is secular and the internal space is sacred. Therefore, the cathedral precinct serves as a valuable buffer space to prepare people for entry into the sacred space. Myeong-dong Cathedral for mass service is in the center of the precinct. The Catholic center, presbytery, the Archdiocese office, the Archdiocese museum, Coste Hall (a multi-purpose hall), and Familia Chapel (a wedding chapel) surround the cathedral. The precinct also includes parking lots and other facilities. The landscape design of this cathedral precinct included vegetation between all of the buildings.

As part of the Myeong-dong Cathedral master plan (Phase 1), the access road was vegetated. It was finalized in October 2014 after three years of construction. Soundscape assessment was performed through social surveys, and in-situ field measurements of sound pressure levels and RT were conducted before vegetation covered with soil and after placement of the vegetation.

2. Methods

2.1 Study area

The access road on the slope from Myeong-dong Cathedral to the cathedral precinct was investigated in this study. Myeong-dong Cathedral is the symbolic headquarters of the Korean Catholic Church and is in the center of Seoul, where a transportation hub, administrative facilities, and commercial buildings are located.

The access road to the slope in front of the cathedral is a public open space, newly developed according to the Myeong-dong Cathedral master plan (Phase 1) and constructed over 37 months starting in September 2011. The renovation project focused on building parking lots to limit the exposure of the cathedral to vibrations caused by cars; establishing an office building for the diocesan curia of the Roman Catholic Archdiocese of Seoul, with 10 floors above ground and four underground; and making the access road from Myeong-dong Cathedral to the rest of the cathedral precinct open to the public.

The access road, shown in Fig. 1, was designed to be pedestrian-friendly and to include vegetation, with large stairs to facilitate access and benches for repose. Vehicles do not use the road unless they are authorized for special occasions in the cathedral. Only pedestrians use the road most of the time, so “pedestrian-friendly” means that the road is normally used by people. Therefore, the road does not include vehicles and was instead created as a multi-purpose space for the enjoyment of the visitors. The access road is an irregularly shaped plane with an area of 2,464 m² and a gradient of 10.15°.

2.2 Vegetation plan

A landscape architect designed vegetation along the access road to harmonize with the scenery and neighborhood surrounding the cathedral. The vegetation was planted along the slope of the access road. The slope has many different layers, as shown in Fig. 2(a). There are

also various kinds of vegetation, and which are listed in Appendix 1. For example, shrubs were established at the entry of the access road to the slope and tall trees were planted close to the cathedral precinct to enhance the natural landscape. This design established multiple layers of vegetation on the low hill, as well as benches and pedestrian stairs on the access road. Under the access road, convenience facilities such as a Catholic support facility, meeting room, souvenir shop, bakery, coffee shop, and bookstore are located on basement level 1 and the parking lot is located on basement level 2 and 3, as shown in Fig. 2(b). The level difference between the Cathedral Square and the main road was around 10.6 m as shown in Fig 2(b). Fig. 3 depicts the access road landscape before vegetation covered with soil, one month after vegetation, and four years after vegetation [32].

(a)

(b)

Fig. 2. (a) Vegetation plan for the slope in front of Myeong-dong Cathedral with a key to the vegetation types provided in Appendix 1 and (b) vertical cross-section of the access road to the slope in front of Myeong-dong Cathedral after vegetation.

(a)

(b)

(c)

Fig. 3. Access road landscape (a) before vegetation covered with soil, (b) one month after, and (c) four years after vegetation.

2.3 In-situ field measurements

To evaluate the effects of vegetation on acoustic environment, acoustical measurements were taken at the same position along the access road before vegetation covered with soil and after vegetation. These measurements were intended to investigate how the sound propagation characteristics differed between before vegetation covered with soil and after vegetation. To minimize the effects of background noise on the calculated acoustic

parameters and signal-to-noise ratio, the acoustic measurements were conducted at night because the Myeong-dong Cathedral area is often very crowded with both people and cars. The measurements were acquired from 8 p.m. to 11 p.m. on Tuesday, June 10, 2014, and on Tuesday, July 15, 2014, which were before vegetation covered with soil and one month after vegetation, respectively, when the temperature and relative humidity were 22.7°C and 65.3%, and 27.8°C and 76.5%, respectively. Four years later, measurements were conducted at the same measurement position from 8 p.m. to 11 p.m. on Friday, June 29, 2018, when the temperature was 23.1°C and the relative humidity was 77.8%.

The reverberation time (RT) and speech transmission index (STI) were measured according to ISO 3382-2 [33] and IEC 60268-16 [34], respectively. The background noise level and sound level reduction by source-to-receiver distance were measured according to ISO 1996-2 [35]. The measurement instruments included a maximum length sequence sound signal and an omni-directional loudspeaker (Type DO12, AVM) with a digital recorder (DA-20, Rion). The measurements were taken at a height of 1.5 m, and ½-inch microphones (GRAS 46AE) were used. Fig. 4 shows the sound source and receiver positions along the access road.

The positions of the sound sources and the number of measurement points were chosen by considering the scale and form of the access road. The sound sources were accordingly installed at the bottom (S1) of the road, and 10 measurement points (R1–R10) were designated in 5 m intervals in the direction of the human traffic flow from the bottom to the top of the access road.

(a)

(b)

Fig. 4. Sound source and receiver positions along the access road: (a) top view and (b) vertical cross-section.

2.4 Social surveys

Social surveys were conducted using questionnaires to compare visitor perceptions of the access road before and after renovation. The subjective satisfaction regarding the religious and social functions in the cathedral precinct was evaluated based on the experiences of the participants in the precinct over the last 12 months or throughout the survey. Thus, even though the surveys were conducted at different times of the day compared to the acoustic measurements, the survey participants evaluated the overall satisfaction of the place rather than that of the place on a specific day. The first survey was conducted with 28 participants (male = 11, female = 17, $M_{age} = 35.7$, $SD_{age} = 11.5$) in August 2013, before starting the renovation, and the second survey was performed with 27 different participants (male = 11, female = 16, $M_{age} = 36.6$, $SD_{age} = 11.2$) in July 2018, after the vegetation had been established for four years. Among the 55 participants, there were nine participants in their 20s (16.4%), 27 participants in their 30s (49.1%), nine participants in their 40s (16.4%), and 10 participants in their 50s (18.1%). All 55 participants were responsible for office work related to the Myeong-dong Cathedral precinct, such as press and public relations, building management, facility operation, and cathedral newspapers, and worked in Myeong-dong Cathedral between 2013 and 2018. Thus, all participants had a deep understanding of the Myeong-dong Cathedral precinct and experienced the cathedral precinct both before and after the renovation, so they were fully aware of the religious functions of the place. When the survey began, an explanation of its purpose was provided.

The questionnaire consisted of two parts. In the first part, the satisfaction of the participants with the access road spatial functions was evaluated. Based on a previous study [6], the spatial functions of the religious precinct were characterized as religious or social. Myeong-dong Cathedral is located in the downtown area, and the Myeong-dong Catholic cathedral precinct, including the cathedral itself, also serves as a public place in downtown,

such as a park. Therefore, the Myeong-dong Catholic Cathedral precinct can be regarded as a tranquil environment that provides relaxation [36–39] or stress relief before religious and social functions. As its religious functions, it serves as a place for religious events, prayer and self-reflection, and tranquility. As its social functions, it acts as a location for social events, formal meetings, informal gatherings, and personal relaxation. The participants were asked to evaluate their satisfaction with the cathedral access road as follows (translated from Korean): “Please rate your satisfaction with the religious/ social functions of this access road to Myeong-dong Cathedral, separately.” The second part of the questionnaire included a set of questions about three environmental components: perceived overall environment including acoustic and visual qualities, acoustic qualities, and visual qualities.

The levels of satisfaction of the participants with all spatial functions and environmental qualities were assessed using a five-point scale (1: very dissatisfied, 2: dissatisfied, 3: neither satisfied nor dissatisfied, 4: satisfied, and 5: very satisfied).

3. Results

3.1 Field measurements

Fig. 5 shows the relative sound pressure levels as functions of source-to-receiver distance in terms of the three different measurement periods: before vegetation covered with soil, one month after, and four years after vegetation. The measurement results show that the relative sound pressure level was the lowest in the before vegetation covered with soil because of the high sound absorption of soils [40–43]. The sound levels acquired one month after vegetation decrease in a manner similar to those before vegetation covered with soil up to a distance of 10 m from the sound source; however, the difference in sound level attenuation between the two measurement periods becomes larger as the source-to-receiver distance exceeds 15 m, which is attributable to the high absorption coefficient of soil. Yang et al. [43] showed that the random-incidence absorption coefficients of soil were ~ 0.9 at 1 kHz. Particularly, at a source-distance of 30 m, the relative sound level measured one month after vegetation is 10 dB greater than before vegetation covered with soil.

The measurement results obtained four years after vegetation are similar to those acquired one month after vegetation up to a distance of 35 m from the sound source, although the relative sound pressure level decreases less, by up to 8 dB at 50 m, depending on the source-to-receiver distance, when compared to one month after vegetation.

Fig. 5. Relative sound pressure level as a function of source-to-receiver distance on the access road.

Fig. 6 shows the measured sound pressure levels according to the source-to-receiver distance by frequency band. Before vegetation covered with soil, the sound pressure level in most frequency bands decreases almost constantly with increasing source-to-receiver distance. This decrease can be considered as simply being due to the noise attenuation effect over distance because trees were not present before vegetation covered with soil. One month after vegetation, the sound pressure level in the range of 250–500 Hz decreases more than in other bands with increasing source-to-receiver distance. Four years after vegetation, the measured sound pressure levels are similar to those before vegetation covered with soil and one month after vegetation up to a distance of 20 m; at distances farther than 20 m, the sound pressure levels in the low-frequency band at 125 Hz decrease 12 dB less than in the previous conditions.

(a)

(b)

(c)

Fig. 6. In-situ test results of sound pressure levels in a one-third octave band according to source-to-receiver distance: (a) before vegetation covered with soil, (b), one month after, and (c) four years after vegetation.

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Fig. 7 shows the measured RT in the 500 Hz and 1000 Hz bands according to measurement position. The RTs range from 1.2 s to 2.4 s before vegetation covered with soil and one month after vegetation and from 1.1 s to 1.3 s four years after vegetation. The RT four years after vegetation is lower than those before vegetation covered with soil and one month after vegetation at all measurement positions. The RTs at measurement positions 7 and 8 are higher than the others, because there is a stair entrance (cube shape glass in the center of Fig. 3) made of thick glass near measurement position 6, which causes strong reflection and affects the RTs at measurement positions 7 and 8.

Fig. 7. In-situ RT test results at (a) 500 Hz and (b) 1000 Hz.

Fig. 8 shows the STI measurement results in the 500 Hz and 1000 Hz bands according to measurement position. The overall tendencies of the STI measurement obtained before vegetation covered with soil and one month after vegetation are similar. The average STI at the 10 measurement positions is 0.33 at 500 Hz before vegetation covered with soil and one month after vegetation and varies between 0.29 and 0.38 at 500 Hz according to the measurement position. The STI measured at 500 Hz four years after vegetation varies between 0.34 and 0.39, and the average of the values obtained at the 10 measurement positions is 0.37. The STI obtained four years after vegetation is higher than those before vegetation covered with soil and one month after vegetation.

Fig. 8. In-situ STI values according to the measurement positions at (a) 500 Hz and (b) 1000 Hz.

In addition, the measured background noise levels during the day before and after renovation were compared, and the sound pressure level difference between before and after renovation was determined to be 5 dB at the cathedral square (measurement position 10), as shown in Fig. 9 [6].

Fig. 9. Background noise levels before and after renovation.

3.2 Survey results

Fig. 10 shows the mean scores of survey participant satisfaction with the spatial functions (religious and social) and perceived environmental quality (overall, acoustic, and visual). To determine if there were significant differences in perceived satisfaction with the access road before and after renovation, the survey responses were statistically analyzed. Shapiro–Wilk tests were performed first to examine the normality assumption for all subjective attributes, and the results showed that all subjective attributes violated the normality assumption. Therefore, the Mann–Whitney U test was applied as a nonparametric alternative to the independent t-test to examine statistically significant differences in the perceived satisfaction of the access road between before and after renovation.

Fig. 10. Mean scores of subjective satisfaction with spatial functions and perceived environmental qualities. The error bars indicate standard deviations, and the asterisks indicate statistically significant differences in mean scores between groups according to post-hoc testing ($*p < 0.05$).

Fig. 11. Percentages of participants who responded with satisfaction ratings of four or five on the five-point scale.

The Mann–Whitney U test showed that there were no statistically significant differences in participant satisfaction with social and religious functions between before and after renovation. These results are attributable to the lack of a significant change in satisfaction with the spatial functions of the access road between before and after renovation because the value of the access road as a space permitting entrance to the cathedral was unchanged, as it was not a characteristic of the renovation. Regarding the perceived environmental qualities, there were statistically significant improvements in perceived overall and acoustic quality at the $p < 0.05$ significance level. No significant mean differences in perceived visual quality between before and after renovation were found.

Additionally, the percentages of participants who responded with “4: satisfied” or “5: very satisfied” for each attribute on the five-point scale, which can be defined as the percentage of satisfaction, are shown in Fig. 11. Similar to the results of the Mann–Whitney U test, the percentages of satisfaction regarding religious and social functions were similar before and after renovation. There was only an approximately 1% improvement in satisfaction with

308 religious and social functions after renovation. After renovation, the percentages of
309 participants satisfied with the overall environmental quality and with the acoustic quality
310 increased by 22.9% and 26.7%, respectively. There was an 8.2% improvement in satisfaction
311 after renovation.

4. Discussion

Acoustic parameters, including relative sound pressure level with distance, RT, and STI were compared among before vegetation covered with soil, one month after vegetation, and four years after vegetation. The results of a soundscape survey between before and after renovation were compared. The sound propagation characteristics were found to have changed.

The relative sound pressure level showed a decreasing tendency compared to the theoretical relative sound pressure level even though there were minor differences between before vegetation covered with soil and one month after vegetation. This result can be explained by the fact that the surface textures before vegetation shown in Fig. 3(a), which included a mixture of sound-absorbing soil sections and sound-reflecting sidewalk blocks, resulted in an irregular decrease in the sound pressure level. However, the relative sound pressure level four years after vegetation was greater than the theoretical relative sound pressure level by 4.8 dB at 40 m, which is similar to the noise reduction of a tree belt [44]. These results were attributed to the increasing density of trees over time, as shown in Fig. 3(c).

Four years after vegetation, the sound pressure level at low frequencies decreased with increasing source-to-receiver distance, as shown in Fig. 6(c). According to a previous study in which the sound energy scattered by a single tree was quantified [45], the effects of vegetation on the relative sound pressure level in each frequency band can be expected to be different depending on the type of vegetation. Therefore, the measurement results shown in Fig. 7(c) were attributed to the changes in the tree height, crown diameter, crown area, leaf size, trunk diameter, and distance from the ground to the bottom of the crown, all of which increased significantly over the four years of tree growth, as shown in Fig. 3.

The long RTs measured before vegetation covered with soil and one month after vegetation are attributable to the many sounds reflected by the buildings surrounding the access road

area, as can be seen in Fig. 4; in contrast, four years after vegetation, the trees close to the sound source were larger and their leaf canopies were thicker, blocking many of the reflected sounds and resulting in relatively short RTs. These results are similar to those reported following a previous study in which the RT response to the shapes of surrounding buildings in an apartment complex was investigated [46]. Thus, the installation of vegetation on the slope in front of Myeong-dong Cathedral increased the STI, which is a significant benefit for those engaging in personal conversations or attending public events in the outdoor space.

There were no significant differences in satisfaction with the religious and social functions between before and after renovation in the cathedral precinct. Jeon et al. [6] showed that open spaces for relaxation and social activities significantly contribute to the social functions in a cathedral precinct. In addition, visual components, including enclosed scenery and religious symbols, are closely associated with the function of religious activities. This characteristic implies that only planting vegetation and landscaping without considering visual components related to social and religious activities might not be able to improve the satisfaction with social and religious functions. In future studies, various design components need to be investigated to enhance social and religious functions in urban religious spaces. Meanwhile, the significant improvement in satisfaction with the acoustic quality of the area was considered to reflect the perceived noise reduction after vegetation, as well as enhanced satisfaction with the overall environmental quality of the area.

The background noise levels reported by Jeon et al. [6] were measured before the renovation of the Myeong-dong Cathedral precinct. Before renovation, the access road was covered with asphalt, and there was no barrier between the main road and the cathedral square [6]. Therefore, the noise from the main road could reach the cathedral square directly. However, the noise from the main road could not reach the cathedral square directly four years after vegetation because there was a vegetation barrier along the access road between

362 the cathedral square and the main road. The background noise level in front of the cathedral
363 square after renovation was reduced compared with before renovation. This finding indicates
364 that the enhancement in the subjective satisfaction with the acoustic and overall
365 environmental qualities might also be related to the physical background noise reduction after
366 renovation.

5. Conclusions

In this study, the acoustic effects of vegetation introduced along the access road to an urban religious space were investigated. This space is intended to provide Catholics and visitors with a restful and enjoyable landscape, establishing a buffer space between the religious functions of the Cathedral precinct and the surrounding urban environment, and improving the acoustic environment to enhance the tranquility of the religious area by reducing noise. One month after vegetation, the relative sound pressure level decreased significantly at a distance of 10 m or more from the sound source compared to before vegetation covered with soil. After four years, as the vegetation was established, the relative sound pressure level tended to reduce more, particularly in the high frequencies. Furthermore, before vegetation covered with soil and one month after vegetation, the RTs were as long as 1–2 s at most measurement points because of the sound-reflecting effects of the surrounding buildings. As the planted trees grew and their leaf canopies became thicker, the RT decreased to approximately 1.2 s because of the sound-absorbing effect of the vegetation. In addition to the physical measurements, surveys were conducted before vegetation covered with soil and after vegetation, over a time span of five years. The survey results showed that participant perception of the overall quality and acoustic quality increased at statistically significant levels, and that the visual quality also increased.

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515 Appendix 1. Vegetation key for Fig. 2 (a).

Group	Pattern	Type of tree	Dimensions (H: height, W: width, both in m)	Amount (unit: stock)	Remarks
Evergreen shrub		Spindle tree	H: 0.3, W: 0.3	750	20 stocks/m ²
Summer-green shrub		Willow-leaf spirea	H: 0.6, W: 0.3	1,440	20 stocks/m ²
	Ilex serrata	H: 1.5, W: 0.6	55	-
	Golden-twigg dogwood	H: 1.0, W: 0.4	880	20 stocks/m ²
	White royal azalea	H: 0.3, W: 0.3	3,320	20 stocks/m ²
	Korean early lilac	H: 1.5, W: 0.6	27	-
	Climbing rose	H: 1.5	200	3 stocks/m
	Rose	4-years old, 3 types	400	20 stocks/m ²
	Bridal wreath	H: 0.6, W: 0.3	1,830	20 stocks/m ²
	Winged euonymus	H: 0.6, W: 0.3	2,530	20 stocks/m ²
	Red-bark dogwood	H: 1.0, W: 0.4	2,770	20 stocks/m ²
	Ginger plant	H: 1.2, W: 0.6	200	10 stocks/m ²
	Pyracantha	H: 1.0, W: 0.3	555	20 stocks/m ²
	Grandiflora	H: 0.6, W: 0.3	440	20 stocks/m ²
	Nandina	H: 0.8	560	10 stocks/m ²
	Cherry tree	H: 1.2, W: 0.6	170	10 stocks/m ²
Herbaceous flowers		Boston ivy	0.4 m	2,200	4 stocks/m
	Maple-leaf mukdenia	8 cm	1,100	25 stocks/m ²

	Big blue lilyturf	3 to 5 tillers	3,700	50 stocks/m ²
	Peony	5 to 7 tillers	650	25 stocks/m ²
	Hedera	10 cm	1,250	50 stocks/m ²

516

Evaluation of exterior space environment factor of Myeong-dong Cathedral

Thank you for participating this survey. Part of this research supported by a 2017-Research Grant from Youngsan University (2018000287). This survey was designed to investigate the perceptions of the elements of spatial factors outside the city center. There are three questionnaires in total, and the expected response time is about 5 minutes. Since the results of the survey are anonymous under Article 8 of the Statistical Law, we promise that the characteristics of specific individuals will not be exposed and will only be used for research purposes in accordance with Article 13 (2) of the Statistical Law. Also, if you have any questions that are not answered, please do not hesitate to answer any questions.

Department of Architecture and Plant, Youngsan University

Responsible Researcher: Professor Sung Chan Lee

Cooperative Researcher: Dr. In Hwan Hwang

1. Please mark the item corresponding to your personal information.

1) What is your gender?

① male ② female

2) What is your age?

① 10 units ② 20 units ③ 30 units ④ 40 units ⑤ 50 units or more

3) What is your occupation? ()

4) What is your religion?

① Catholic ② Protestant ③ Buddhist ④ Other () ⑤ No religion

5) What is the purpose of your visit to Myeong-dong Cathedral?

① Work, business ② Attend religious events ③ Attend social events ④ Travel, sightseeing

⑤ Others ()

6) How often do you visit Myeong-dong Cathedral?

Everyday	1-2 times a week	Once a month	Once every six months	Less than once a year

7) How interested are you in urban environment?

I do not care much	Usually			I am very interested
1	2	3	4	5

8) What is your personal noise sensitivity?

I do not care much	Usually			I am very interested
1	2	3	4	5

2. Please rate your satisfaction with the religious/ social functions of this access road to Myeong-dong Cathedral, separately. What important function of the cathedral entry space do you think is important? The access road to Myeong-dong Cathedral means the green space that passes through the Myeong-dong Cathedral before passing through the Myeong-dong Cathedral. (1 means that it is not important at all, 3 means that it is usually important, and 5 means that it is very important.)

☐ **Religious function**

1) Space for the separation between urban and religious spaces

(Recognized as a religious space from the entrance of the cathedral)

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

2) Space for the accommodation various religious events

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

3) Space for the prayer and self-reflection

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

4) Tranquil space (tranquility: quiet feeling, pleasant sight, pleasant feeling in the five senses such as comfortable tactile sense or psychological stability, and satisfaction with strong religious characteristics)

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

☐ **Social function**

5) Space for the connection the city center with the religious space

(The access road to Myeong-dong Cathedral is a preparation space with strong social characteristics)

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

6) Space for the accommodation social events and meetings

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

7) Space for the meeting and communication

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

8) Space for the private rest

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

9) Comfortable space (Psychological comfort that the religious character is not strong)

Function importance	It does not matter at all		Usually		Very important
	1	2	3	4	5
Current satisfaction	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
	1	2	3	4	5

3. Please rate your satisfaction with the acoustic environment (noise level, acoustic comfort) of the current access road to Myeong-dong Cathedral.

(1 means that it is not very satisfied, 3 means that it is usually satisfied, and 5 means that it is very satisfied)

Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
1	2	3	4	5

4. Please rate your satisfaction with the spatial environment (convenience of space, visual comfort) of the access road to Myeong-dong Cathedral.

(1 means that it is not very satisfied, 3 means that it is usually satisfied, and 5 means that it is very satisfied)

Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
1	2	3	4	5

Appendix 1. Vegetation key for Fig. 2 (a).

ACCEPTED MANUSCRIPT					
Group	Pattern	Type of tree	Dimensions (H: height, W: width, both in m)	Amount (unit: stock)	Remarks
Evergreen shrub		Spindle tree	H: 0.3, W: 0.3	750	20 stocks/m ²
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	White royal azalea	H: 0.3, W: 0.3	3,320	20 stocks/m ²
	Korean early lilac	H: 1.5, W: 0.6	27	-
	Climbing rose	H: 1.5	200	3 stocks/m
	Rose	4-years old, 3 types	400	20 stocks/m ²
	Bridal wreath	H: 0.6, W: 0.3	1,830	20 stocks/m ²
	Winged euonymus	H: 0.6, W: 0.3	2,530	20 stocks/m ²
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	Pyracantha	H: 1.0, W: 0.3	555	20 stocks/m ²
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	Peony	5 to 7 tillers	650	25 stocks/m ²
	Hedera	10 cm	1,250	50 stocks/m ²

Highlights

- The effects of vegetation in Cathedral precinct on noise reduction and soundscape were investigated.
- The relative sound pressure level decreased less due to vegetation growth after four years.
- Reverberation time decreased to 1.2 s due to sound absorption by the vegetation.
- Perception of overall environmental quality, and acoustic comfort improved after vegetation.