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Research on urban landscape design using the interactive genetic algorithm and 3D images

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Abstract

Background: Generally, there are different optimal solutions with regard to urban landscape planning depending on the area and the opinions and characteristics of community residents. Furthermore, when considering urban landscape and/or city-planning regulations, it is important to include residents' opinions based on voluntary activities like participation in town development on a regional scale and its management. However, residents' opinions are difficult to quantify, as many do not have specialized knowledge. Therefore, when an administrative body plans a city, a system to include residents' opinions on urban landscape options is required.

Methods: In this study, an optimization system for urban landscape design was proposed using an interactive genetic algorithm (IGA). In this system, three properties of an urban landscape, that is, wall surface positions, heights, and building textures, were varied and the resulting urban landscape images, developed using OpenGL, were subjectively evaluated by users. Weighted scores were then calculated using the paired comparison method. In this system, a site of 200 m × 70 m was assumed and 20 buildings were located on 20 m × 20 m lots. The building widths were fixed at 20 m, and wall positions from the sidewalk varied from 10 m to 20 m at 2 m intervals. The building heights varied from 20 m to 40 m at 4 m intervals, and eight building textures were considered. Two simulations were performed: Case 1, in which the three parameters were evaluated simultaneously; and Case 2, in which the three parameters were evaluated individually. The same 10 users participated in both cases. Following completion of each case, questionnaires were administered to users in which they were asked to confirm that the results obtained matched their expectations.

Results: The results demonstrated that individual users were satisfied with the results generated based on their evaluations. In both cases, the results were obtained from the optimal results of the system as the result of questionnaires.

Conclusions: It is necessary to re-examine the evaluation order and evaluation method used as evaluation order may affect optimal results. Furthermore, since users generated different optimal results, it is necessary to develop an optimization system for urban landscapes that allows for collaboration between users.

Keywords: Interactive genetic algorithm, Urban landscape, Paired comparison method

Background

The urban landscape comprises the cityscape and scenery inherent to a region and has various characteristics. Local governments enact urban landscape regulations and must consider residents' opinions during voluntary activities in the development of urban landscape and/or city-planning. When urban landscape design is understood to be an optimization problem, the optimal solution may differ depending on the region and is influenced by the opinions and characteristics of the residents. However, many community residents do not have specialized knowledge; therefore, when a given administration plans a city, a system to include residents' opinions regarding urban landscape options is required. In the field of urban planning, previous research has focused on the basis for decision support in inner-city development (Seifert, Mühlhaus, and Petzold 2016), computer aided zoning and urban planning (Garyaev 2014), a 3D visualization system (Tan, Fan, and Deng 2011), and the role of procedural modeling (Luo and He

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2016). Moreover, studies have been conducted into the optimization and development of support tools to solve complex urban planning or landscape problems. For example, in building design using the Genetic Algorithm (GA), previous studies have examined floor shape optimization for green building design (Wang, Rivard, and Zmeureanu 2006) and three-dimensional shape generation for low-energy architectural solutions (Caldas 2005). However, this research concerned environmental aspects rather than subjective evaluations as the constrained condition. Research has also been conducted into the conceptual design of commercial buildings using GA (Miles, Sisk, and Moore 2001), concerning, for example, the floor plan and layout of columns based on a large number of criteria, including lighting requirements, ventilation strategies, limitations introduced by the available sizes of typical building materials, and the available structural systems. GA has also been used to devise a solution to the unequal area facilities layout problem (Wang, Hu, and Ku 2005). Thus, it can be seen that previous GA research has focused on the shapes, column layout, and facilities layout of buildings, the design of building facades including the multi-criteria decision-making process (Raphael 2014), and the development of support tools for decision making. Finally, Kawano and Tsutsumi (2011) developed the design idea generation support system for the facades of office buildings. However, studies aimed at the streetscape of office buildings or a wider range of urban landscape elements have not yet been conducted. Therefore, when an administrative body is planning a city, it is necessary to develop a support system that targets not only a specific building but also the entire streetscape in order to create consensus between administrative bodies and residents who lack architectural knowledge, based on the subjective evaluation of the latter. In this research, in particular, such a system is developed based on evaluation from a pedestrian perspective. To create consensus between administrative bodies and residents, this system presents images and the appearance of a completed urban landscape, and facilitates the administrative bodies and residents to share complex images. In addition, the system enables both groups to easily point out a problem or an improvement because they can share the image in the process of consensus. It is envisaged that, in the future, when an administrative body plans a city, they may use this system to consider residents' opinions.

Interactive Genetic Algorithm (IGA)

This research uses an interactive genetic algorithm (IGA) (Smith 1991) to propose an optimization system for urban landscapes as a means to incorporate a human, subjective assessment into the optimization system. IGA is a method of Evolutionary Computation (EC) such as GA and, more specifically, a method of Interactive Evolutionary Computation (IEC) (Takagi 1998). IGA replaces evaluation with the subjective evaluation of users based on the genetic operations of GA; it is generally applied to the generation of music or designs, which are difficult to evaluate quantitatively, as a means to analyze the complex structure of human sensibility. Previous applications of IGA research include Takagi and Ohya's (1996) study on "Discrete Fitness Value for Improving the Human Interface," 3-D CG Lighting (Aoki and Takagi 1997), and fashion design (Kim and Cho 2000; Guo, Gong, Hao, and Zhang 2006; Gong, Hao, Zhou, and Sun 2007; Gong, Guo, Lu, and Ma 2008; Gong, Yuan, and Sun 2011). IGA has also been applied to creativity enhancement tools (Kelly, Papalambros, and Seifert 2008), while Farooq and Siddique conducted a comparative study of user interfaces using IGA (Farooq and Siddique 2014). IGA research has also been conducted into the color combination system of signboards to blend with the landscape, in an attempt to construct a signboard color combination support system using human subjective evaluation (Inoue and Inoue 2010). Finally, a furniture design support system (Takizawa, Kawamura, and Tani 2000) has also been created. Thus, as seen from the previous research, IGA has already been applied to various architectural problems. In this study, the parameters employed are wall surface positions, heights, and building textures in the creation of an urban landscape; in using these parameters, we consider the feeling of pressure on roads and pedestrians, height regulations, and façade design, which are elements that feature heavily in the impression of buildings. We have limited this study to these three evaluation elements in order to simplify the system and users' evaluations. Urban landscape images were created using OpenGL, and users evaluated these images with a weighted score that was calculated using the paired comparison method (Satty 1980). In this study, 10 users participated in a process of evolutionary computing, using an IGA to progressively optimize the landscape. Finally, the users completed questionnaires to confirm that the results obtained matched their expectations. The questionnaires, which were completed after the users had completed their design decisions, were used to verify the effectiveness of the system. In past research (Koma, Yamabe, and Tani 2016), optimal results were also considered with regard to the characteristics of each case and the effectiveness of this system was verified. Furthermore, in this study, the characteristics of users' choices were considered by selecting the considered elements in order to more clearly analyze and classify the characteristics of the optimal results.

Methods

In this study, urban landscape images, which form the basis of the IGA evaluation, were created using OpenGL. As shown in Fig. 1, Kyomachi-suji Street at Chuo-ku in Kobe City was selected as the model streetscape for the office buildings shown, while the designated parameters

Fig. 1 Kyomachi-suji Street at Chuo-ku in Kobe City

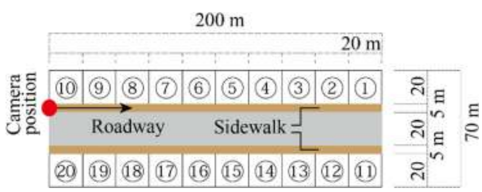

Fig. 2 Setting of site

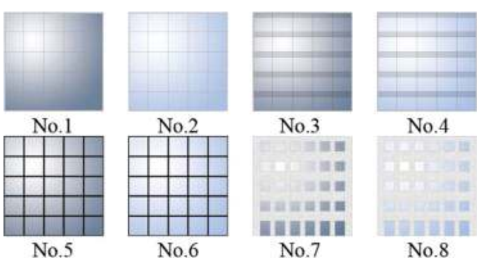

Fig. 3 Setting of textures

Fig. 4 Example of the walk-through video (starting position, 0 m)

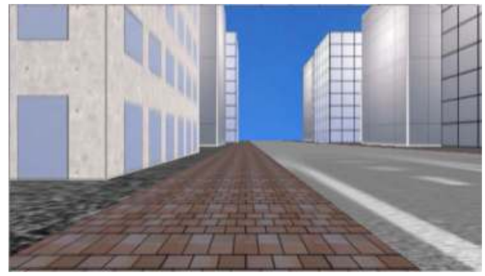

Fig. 5 Example of the walk-through video (30 m from starting position)

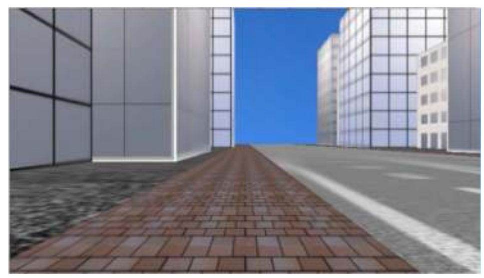

Fig. 6 Example of the walk-through video (60 m from starting position)

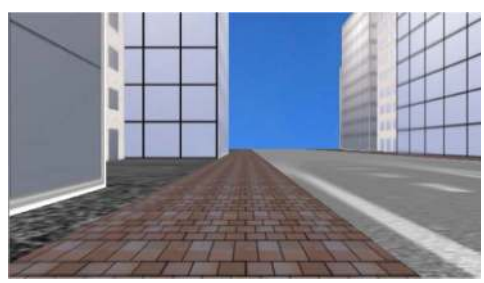

Fig. 7 Example of the walk-through video (90 m from starting position)

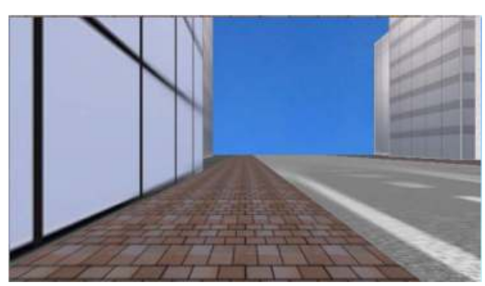

Fig. 8 Example of the walk-through video (120 m from starting position)

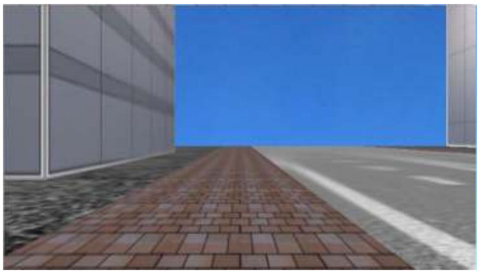

Fig. 9 Example of the walk-through video (150 m from starting position)

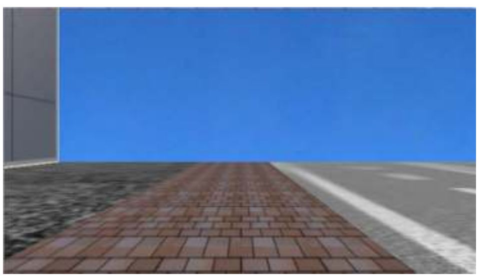

Fig. 10 Example of the walk-through video (180 m from starting position)

of the site were 200 m × 70 m (Fig. 2). These parameters were selected in consideration of the fact that the length of one block on this street is approximately 200 m, which represents the approximate distance that a person can see at first observation. Twenty buildings were arranged at the site on 20 m × 20 m lots in consideration of the width of the targeted site, which is approximately 20 m to 30 m. The boundaries of building sites were set at 20 m from the upper and lower edges of the site, and the sidewalk was 5 m wide. The building dimensions were X (width), Y (depth), and Z (height). The widths X of all buildings were fixed at X = 20 m, and the depths (wall positions from the sidewalk) varied from 10 m to 20 m at 2 m intervals, while the heights varied from 20 m to 40 m at 4 m intervals. Eight building textures were available (Fig. 3), and each texture was displayed in six different ways, depending on the number of stories (Z/4). To simplify the method, buildings 11 to 20 were created as mirror images of buildings 1 to 10. In this system, plants and other elements were not considered and plans were evaluated with respect to just three elements: wall positions, heights, and textures. In the actual urban landscape formation, due to the limitations of the building coverage and floor-area ratios, wall positions and building heights are considered to have certain relationships. However, this study evaluates only the shapes of buildings and adjacency to each other as seen by pedestrians. It is considered that evaluating urban landscapes is difficult because multiple buildings are evaluated simultaneously. Thus, the optimization system's setting is simplified to ensure easy evaluation and the aspects of buildings that are examined are limited to wall positions, heights, and textures. When evaluating an urban landscape, it is important to do so from a pedestrian's perspective because in perceiving the atmosphere of a city, we more often walk the streets than look at photographs of the city. Therefore, the urban landscapes were depicted realistically using a walk-through video of the site. The video simulated walking along a sidewalk, as indicated by the arrow, from the far left to the far right. The camera height was set at 1.5 m, which is the average height of a human eye. Examples of continuous images of the walk-through video are shown in Figs. 4, 5, 6, 7, 8, 9 and 10.

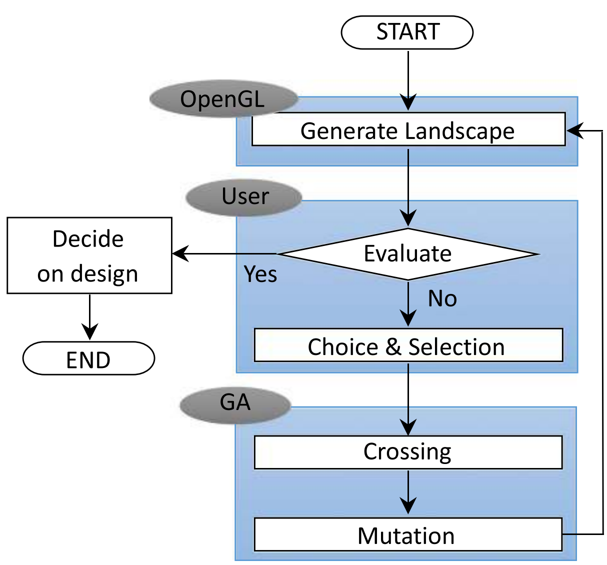

Fig. 11 IGA flow chart

Setting of IGA

In this system, the application of genetic operations allowed the urban landscapes to evolve, using input from the users' cyclical evaluations of the landscapes depicted. Variability came from the wall positions, heights, and textures of buildings. The urban landscape images were generated using OpenGL and shown to users. Using the paired comparison method, users evaluated the displayed urban landscapes. The system then used the weighted scores from paired comparison and a genetic algorithm (GA) to generate new urban landscapes. Figure 11 shows the IGA flow chart.

Table 1 Expression in G-type

Genetic locus	0	1	2	3	4	5	6	7	8	9
Chromosome	10	16	14	20	10	18	12	18	14	10
Genetic locus	10	11	12	13	14	15	16	17	18	19
Chromosome	32	40	32	36	20	32	36	40	24	28
Genetic locus	20	21	22	23	24	25	26	27	28	29
Chromosome	13	35	83	64	70	13	54	85	61	32

The G-type (genotype) used in this system was a series of decimal numbers as shown in Table 1. Numbers 0 to 9 in the genetic locus express the wall positions (in meters) of buildings 1 to 10, where the range of wall positions comprises even numbers between 10 and 20. Numbers 10 to 19 in the genetic locus express the heights of buildings 1 to 10, where the range of heights (in meters) is in intervals of 4 from 20 to 40. Numbers 20 to 29 in the genetic locus express textures for buildings 1 to 10. The texture chromosomes provided displayed information to OpenGL in two ways. The first digits range from 1 to 8 and correspond to one of the texture images shown in Fig. 3. The second digits range from 0 to 5 and correspond to the height of the building, where 0 indicates a 5-story building (20 m height), 1 a 6-story building (24 m height), continuing up to digit 5, which indicates a 10-story building (40 m height). Consequently, the chromosomes in loci 20 to 29 have values of 10–15, 20–25, 30–35, 40–45, 50–55, 60–65, 70–75, and 80–85. For example, referring to Table 1, building 1 can be described as follows: the wall position is 10 m from the sidewalk, shown by the value 10 in genetic locus 0; the height is 20 m, shown in genetic locus 10; and the value of 10 in genetic locus 20 gives us both texture number 1 (first digit, 1) and a 5-story building (second digit, 0). The details of buildings 2 to 10 were determined in the same manner, and buildings 11 to 20 were symmetrical across the roadway.

In this system, the initial values of depth (Y), height (Z), and texture for each building were set as random numbers in the G-type. A P-type was created based on the G-type shown in Table 1, and urban landscapes as shown in Fig. 12 were generated using OpenGL.

The number of urban landscape plans displayed

One of the practical factors inherent in IGA design is user fatigue, which may occur as users operate the system. Thus, it is necessary to create a system in which users can evaluate urban landscape plans easily. If the number of competing plans shown to users in one generation increases, it is likely that the number of generations required will increase and, in consequence, user fatigue will also increase. Therefore, in this system, four plans were displayed to users in each generation, as shown in Fig. 13.

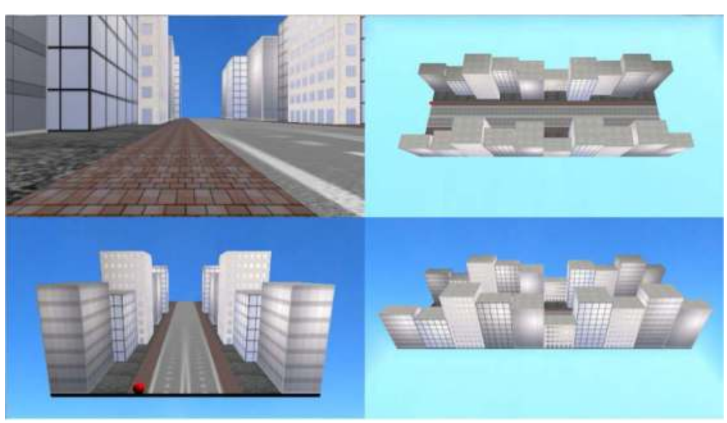

Fig. 12 An example of P-type decoding from G-type

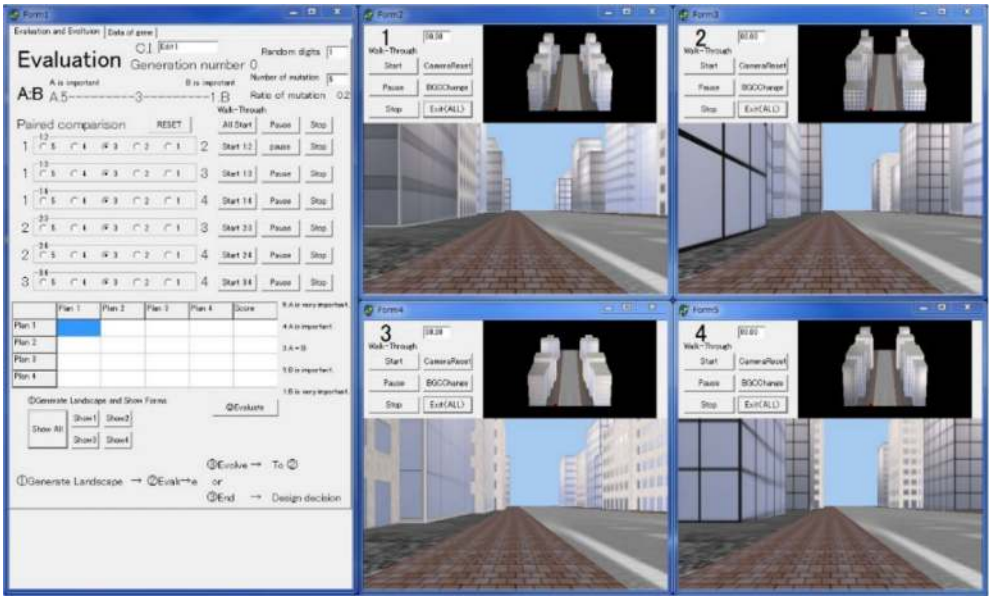

Fig. 13 An example of the user interface

Genetic operations

In this system, scores for the four urban landscape plans were calculated using the paired comparison method and the plans were ranked. The paired comparison method can relieve the burden of judgment on decision-makers, which can, in turn, be reflected in the unquantifiable judgment of human feeling and the consistency of the evaluation can thus be examined. In this research, the scores and order were calculated from the subjective evaluations of the users, and genetic operations were executed using the scores and order. Furthermore, a consistency judgment was made using the scores of the paired comparison method. In this system, the paired comparison method was executed using a five-grade evaluation. For example, when A and B were compared, if users preferred or did not prefer both A and B, the evaluation was designated as 1 as shown in Table 2. In this table, A is greatly preferred, and so the evaluation number is increased. In a contrasting situation, if B is greatly preferred, the evaluation is decreased. If the evaluation of B to A is calculated, the value is reciprocal for the evaluation of A to B. Each comparative evaluation from A to D was calculated as shown in Table 3. In cells in which the same plans are compared, such as A with A, 1 was inserted. In the symmetric cells across the cells, the inverse of the previous evaluation value was placed. The scores were then calculated by comparing for each of A to D, creating a table, and evaluating the geometric mean in the row direction. In this case, the scores were determined in the order of A, D, C, B. According to the ranking conditions, G-Types in the next generation

Table 2 Value of paired comparison method

Value of paired comparison	Evaluation of A to B
3	Users greatly prefer A to B.
2	Users prefer A to B.
1	Users prefer or do not prefer both A and B.
1/2	Users prefer B to A.
1/3	Users greatly prefer B to A.

Table 3 How to calculate evaluation of paired comparison method

	A	B	C	D	Geometric mean	Score
A	1	3	2	2	1.86	0.416
B	1/3	1	1/2	1/2	0.537	0.120
C	1/2	2	1	1/3	0.760	0.170
D	1/2	2	3	1	1.32	0.294

Table 4 Selection methods in genetic operations

Ranking condition	Selection methods
Difference between the best and second best score is greater than or equal to 0.1.	The best G-Type with the greatest score is preserved and 3 other G-Types are generated by the mutation operation to the best G-Type.
Difference between the best and second best score is less than 0.1.	The best G-Type is preserved and 3 other G-Types are generated by crossover and mutation operations between G-Types with the best and second best scores.
There are 2 best scores.	Four new urban landscapes are created by crossing and mutating 2 urban landscapes with best scores.
There are 3 best scores.	Four new urban landscapes are created by crossing and mutating 3 urban landscapes with best scores.
There are 4 best scores.	Four new urban landscapes are created by crossing and mutating 4 urban landscapes with best scores.

Fig. 14 Case 2–2

were generated by the selection methods in genetic operations as shown in Table 4.

Execution conditions

The purpose of this study was to develop a system that administrative bodies can use to evaluate residents' opinions of urban landscape problems. Students who had some experience of learning architectonics but who did not have experience of engaging in urban planning were targeted in this study because they are situated in an intermediate position between administrative bodies of professionals in the fields of architecture and urban planning and the general public. For this study, 10 users, of whom 4 were undergraduate students and 6 were graduate students in the School of Architecture at Kobe University, were engaged to evaluate virtual urban landscape plans. Initial instructions explained orally that users should evaluate only the wall positions, heights, and textures of buildings. All users performed two simulations: Case 1, in which the three parameters were evaluated simultaneously; and Case 2, in which the three parameters were evaluated individually. When users evaluate urban landscapes simultaneously and individually, the result is likely to be different in each case. Furthermore, two simulations (Case 1 and Case 2) were performed in this study because evaluating three factors individually was considered easier than evaluating them simultaneously. In this paper, all results refer to the user number as follows: the results of the n-th user are denoted as Case 1-n and Case 2-n. Users evaluated urban landscape plans based on two screen displays: the 3D bird's-eye diagonal view, and the walk-through video from the pedestrian perspective. In the first round of image generation, four urban landscape plans were generated using randomly defined G-Types, and the evaluation began. Users evaluated these plans using the paired comparison method described above, and genetic operations were then performed based on the evaluation results. The users' consistency was evaluated using a consistency index of less than or equal to 0.1. When the evaluation results were inconsistent, users repeated the evaluation process until a consistent result could be obtained. Once simulations in each case had reached a design decision, users completed five-point Likert-like questionnaires on the usability of the system, their degree of tiredness, the ease of making choices using the paired comparison method, and their degree of satisfaction with the optimal result. The usability of the system was set to ensure maximum ease of use for all users. One of the problems of IGA is that users may become fatigued during use. It is considered that this problem can be solved by setting the system to minimize user fatigue. The ease of making selections is related to the usability of the system, as well as reducing fatigue; hence, this aspect was set appropriately. Finally, satisfaction with the result was set because it is an important feature of the system that users are satisfied with the obtained results.

Fig. 15 Case 2–4

Fig. 16 Case 2–6

Fig. 17 Case 2–7

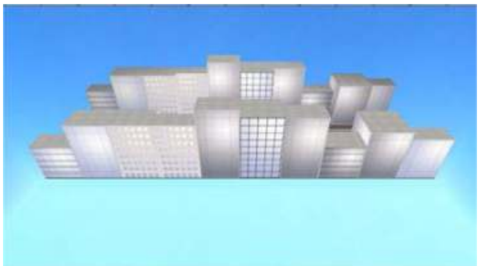

Fig. 18 Case 2–9

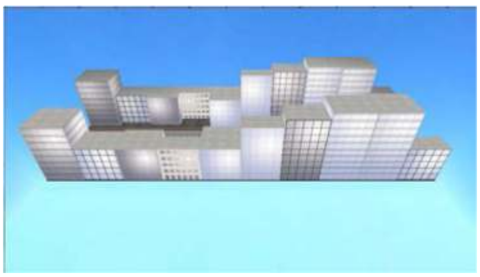

Fig. 19 Case 2–10

Results

Examples of the execution results of the system in Case 2 are shown in Figs. 14, 15, 16, 17, 18 and 19. To obtain the characteristics of the chosen urban landscapes in each case, for the value of chromosomes of the urban landscape, the average, standard deviation (standard deviation 1), and median values of heights of buildings 1 to 10 in Cases 2–2, 2–4, 2–6, 2–7, 2–9, and 2–10 were calculated and are shown in Table 5. The heights of adjacent buildings were also compared; the resulting standard deviation (standard deviation 2) of height differences is shown in Table 5. Table 6 shows the first- and last-generation occurrence frequency of each texture in the results of Cases 1 and 2. The results of the questionnaires and the number of generations for convergence when simulations in each case were terminated are shown in Table 7.

Table 5 Results of case 2 (Heights)

Case	2–2	2–4	2–6
Average	30.4	32.4	23.6
Standard deviation 1	8.04	8.48	4.54
Median value	34.0	36.0	22.0
Standard deviation 2	14.4	13.4	6.53
Case	2–7	2–9	2–10
Average	28.0	30.0	28.0
Standard deviation 1	5.37	6.51	8.39
Median value	32.0	32.0	26.0
Standard deviation 2	8.10	7.88	8.84

Table 6 Execution results for textures in cases 1 and 2

Case 1	Texture Number	4	3	6	7	2	8	1	5
	Rate for the last generation (%)	18	17	16	16	15	7	6	5
	Rate for the first generation (%)	15	12.5	17.5	12.5	10	12.5	10	10
Case 2	Texture Number	7	1	3	8	2	6	5	4
	Rate for the last generation (%)	20	18	15	14	12	12	5	4
	Rate for the first generation (%)	16.5	19.75	9.75	12.5	15.75	10.75	10.25	4.75

Discussion

In Case 1, the optimal results were almost achieved because the average user satisfaction value was 4.2 out of a possible 5, as shown in the questionnaire results in Table 7. The rate of textures for the first generation was relatively equable as shown in Table 6. Textures No. 4 and No. 3 were selected with a similar frequency, as shown in Table 6.

In Case 2, the optimal results were also nearly achieved because the average user satisfaction value was 4.2, as shown in the questionnaire results in Table 7. In Table 6, textures No. 7 and No. 1 were selected approximately 40% of the time. However, the selected ratio of textures in the first generation was biased unlike in Case

Table 7 Summary of questionnaire results and generations to convergence (5 is best)

Evaluation of the system			Case 1	Case 2
	Usability of the system		3.6	3.2
	Less tiredness		3.4	3.6
	Ease of making selections		3.3	3.4
	Satisfaction with the result		4.2	4.2
	Average number of generations to convergence		3.4	5.0
Case 2				
		Wall positions	Heights	Textures
	Details Average of the generations to convergence	2.3	1.8	1.9

1 because of the disproportionate rate of textures for the first generation. It is necessary to examine whether the texture that was finally selected was chosen. As shown in Table 7, the number of evaluations for wall positions was 2.3, for heights was 1.8, and for textures was 1.9. The wall positions evaluated at the beginning were evaluated the most times; thus, it is considered that users may have been too tired or bored to evaluate the urban landscapes as a whole as the number of evaluations increased. That is to say, if the overall number of evaluations was high, the number of evaluations of a given element decreased over time; thus, it is necessary to examine the evaluation order and evaluation method because the evaluation order may have affected the optimal results.

In Cases 2–2 and 2–4, four of the height values (Average, Standard deviation 1, Median value, and Standard deviation 2) were relatively close, as shown in Table 5. In particular, standard deviation 2 in Cases 2–2 and 2–4 displayed a large difference compared to the other cases. Furthermore, the median values in Cases 2–2 and 2–4 were high. The urban landscape in Cases 2–2 and 2–4 had large differences in height as shown in Figs. 14 and 15. Many high buildings were selected in Cases 2–2 and 2–4. Furthermore, the height values of Cases 2–7 and 2–9 were relatively close, as shown in Table 5. The average and median values of Cases 2–2 and 2–9 were also relatively close. However, the standard deviation 1 and 2 in Cases 2–7 and 2–9 showed a large difference compared with Cases 2–2 and 2–4. If the average heights of buildings were close, while, on the other hand, the difference in adjacent buildings was large, users might perceive a different image with respect to their urban landscapes. The urban landscape in Cases 2–7 and 2–9 comprised small height differences and more gradual changes in height, as shown in Figs. 17 and 18. In Cases 2–2 and 2–6, the difference between the average, standard deviation 1, median value, and standard deviation 2 height values was large, as shown in Table 5. In Case 2–2, the heights of buildings in the urban landscape were perceived as jagged as shown in Fig. 14. However, for Case 2–6, the building heights of the urban landscape were perceived as low and their changes were small as shown in Fig. 16. For heights in Cases 2–9 and 2–10, the average and median values that mean average heights of buildings in Case 2–9 were larger than their values in Case 2–10. However, standard deviations 1 and 2, which mean variation in the heights of buildings in Case 2–10, were larger than their values in Case 2–9, as shown in Table 5. In Case 2–9, the building heights in the urban landscape were perceived as high and their changes were small as shown in Fig. 18. However, in Case 2–10, high buildings were also chosen although low buildings were also frequently chosen as shown in Fig. 19. For this reason, the standard deviations 1 and 2 in Case 2–10 were larger than in Case 2–9.

The questionnaire results showed that both feelings of tiredness and ease of making choices were slightly higher for Case 2. Therefore, while individual evaluations were considered easier than simultaneous evaluations, on the other hand, individual evaluations require many generations to reach convergence. Simultaneous evaluations like Case 1 do not require many generations to reach convergence and it is easy to use the system because three parameters are evaluated simultaneously. The characteristics of each case like usability and ease of making selections were identified.

Conclusions

In this study, an optimization system for urban landscape plans was developed and executed for architectural students, employing just three evaluation factors: wall positions, heights, and textures of buildings. The study showed that users' subjective evaluations can be reflected using IGA. The following conclusions were obtained from the optimal results of the system in the two cases.

- In Case 1 and Case 2, users were satisfied with the optimal result generated by the system as the result of questionnaires.
- In the heights of Case 2, the characteristics of each optimal result were identified by comparing 4 values (average, standard deviation 1, median value, and standard deviation 2).
- In Case 1, the optimal result was achieved in fewer generations than in Case 2. In Case 2, users found it easier to make choices and felt less tired. Therefore, the characteristics of each case were identified.
- It is necessary to consider the target and the number of targets because the optimal result for professionals of architecture or the general public has the potential to be different from that for architectural students, as in this study.
- It is necessary to consider an algorithm that can obtain a more optimal urban landscape and construct an analysis method that can numerically summarize users' opinions and optimal urban landscapes, for example, using principal component analysis. Furthermore, it is necessary to create a consensus building method that can reflect plural opinions in real instances of urban landscape design.

In addition, it was noted that the participation of residents in urban planning gives rise to problems concerning consensus, the system used by the residents to participate in urban planning, and inhabitant consciousness. As the first step in addressing these problems, the setting of a target site and factors was simplified, a system that reflects users' opinions regarding urban landscapes was built using IGA, and the characteristics of selected urban landscapes were identified in this study. Since this study considers only the simple evaluation of users and does not spare any thought for cognitive psychology (for example, Gestalt psychology), cognitive psychology could not be introduced in this study. Nonetheless, it is considered that cognitive psychology may be necessary. On the limitation of this study in building a decision support system of subjective human opinions, there is consensus. For example, it is considered that a system providing urban landscapes that can satisfy all residents probably cannot be built; however, it is possible to build a system that provides urban landscapes that can satisfy 70–80% of residents. Finally, by implementing the optimization system among multiple users and creating consensus, residents' participation in urban planning can be made easier, the lack of expert knowledge on the part of residents and difficulties in reflecting their opinions can be overcome, and both residents and administrative bodies can share information and concept values. Therefore, it is considered that better town development can be carried out using this system.

Authors' contributions
SK developed the optimization system, conducted the experiments, analyzed the results of the experiments, and drafted the manuscript. YY and AT assisted in drafting the manuscript, and with the methods of developing the system and analysis. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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References

Aoki, K., & Takagi, H. (1997). *3-D CG Lighting with an Interactive GA* (pp. 296–301). Adelaide: 1st International Conference on Conventional and Knowledge-based Intelligent Electronic Systems (KES'97).

Caldas, L. G. (2005). *Three-Dimensional Shape Generation of Low-Energy Architectural Solutions using Pareto Genetic Algorithms* (Proceedings of eCAADe'05, pp. 647–654).

Farooq, H., & Siddique, M. T. (2014). A Comparative Study on User Interfaces of Interactive Genetic Algorithm. In *The 5th International Conference on Ambient Systems, Networks and Technologies (ANT-2014)* (pp. 45–52).

Garyaev, P. N. (2014). Computer Aided Zoning and Urban Planning. In *Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering* (pp. 1618–1625).

Gong, D.-W., Hao, G.-S., Zhou, Y., & Sun, X.-Y. (2007). Interactive genetic algorithms with multi-population adaptive hierarchy and their application in fashion design. *Applied Mathematics and Computation, 185*, 1098–1108.

Gong, D.-W., Guo, G., Lu, L., & Ma, H. (2008). Adaptive interactive genetic algorithms with individual interval fitness. *Progress in Natural Science, 18*, 359–365.

Gong, D.-W., Yuan, J., & Sun, X.-Y. (2011). Interactive genetic algorithms with individual's fuzzy fitness. *Computers in Human Behavior, 27*, 1482–1492.

Guo, G.-S., Gong, D.-W., Hao, G.-S., & Zhang, Y. (2006). Interactive Genetic Algorithms with Fitness Adjustment. *Journal of China University of Mining and Technology (English Edition), 16*(4), 480–484.

Inoue, H., & Inoue, C. (2010). Color Combination System of Signboards to Blend in with Landscape by Interactive Genetic Algorithm. *Proceedings of SCIS & ISIS, 2010*, 45–49.

Kawano, T., & Tsutsumi, K. (2011). A development on the design idea generation support system for the facade of the office building Part1. Examination of the number of IDE (Interactive Differential Evolution) population choice pattern. *Journal of Japan Society for Fuzzy Theory and Intelligent Informatics, 23*(1), 54–64. in Japanese, abstract written in English.

Kelly, J., Papalambros, P.-Y., & Seifert, C.-M. (2008). *Interactive Genetic Algorithms for use as Creativity Enhancement Tools* (Proceedings of Creative Intelligent Systems (2008 AAAI Spring Symposium), pp. 34–39).

Kim, H.-S., & Cho, S.-B. (2000). Application of interactive genetic algorithm to fashion design. *Engineering Applications of Artificial Intelligence, 13*, 635–644.

Koma, S., Yamabe, Y., & Tani, A. (2016). Research on Urban Landscape Creation by Interactive Genetic Algorithm. In *Proceedings of the 16th International Conference on Computing in Civil and Building Engineering* (pp. 1261–1268).

Luo, Y., & He, J. (2016). The Role of Rule-Based Procedural Modeling in Urban Planning. In *Proceedings of the 16th International Conference on Computing in Civil and Building Engineering* (pp. 1269–1276).

Miles, J. C., Sisk, G. M., & Moore, C. J. (2001). The conceptual design of commercial buildings using a genetic algorithm. *Computers and Structures, 79*, 1583–1592.

Raphael, B. (2014). Multi-criteria Decision Making for the Design of Building Façade. In *Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering* (pp. 1650–1658).

Satty, T. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Seifert, N., Mühlhaus, M., & Petzold, F. (2016). A Parametric 3d City Model: Basis for Decision Support in Inner-City Development. In *Proceedings of the 16th International Conference on Computing in Civil and Building Engineering* (pp. 1285–1292).

Smith, J. R. (1991). Designing Biomorphs with an Interactive Genetic Algorithm. In *Proceedings of the 4th International Conference on Genetic Algorithms (ICGA-91)* (pp. 535–538).

Takagi, H. (1998). Interactive Evolutionary Computation-Cooperation of computational intelligence and human KANSEI–. In *Proceedings of the 5th International Conference on Soft Computing and Information / Intelligent Systems (IIZUKA'98)* (pp. 41–50).

Takagi, H., & Ohya, K. (1996). Discrete Fitness Values for Improving the Human Interface in an Interactive GA. In *Proceedings of 1996 International Conference on Evolutionary Computation* (pp. 109–112).

Takizawa, A., Kawamura, H., & Tani, A. (2000). Furniture Design Support System by Interactive Evolutionary Computing. In *Proceeding of the Second Asia-Pacific Conference on Genetic Algorithms and Applications* (pp. 48–56).

Tan, J., Fan, X.-T., & Deng, F. (2011). Design and Key Technology of Urban Landscape 3D Visualization System. *Procedia Environmental Sciences, 10*, 1238–1243.

Wang, M.-J., Hu, M. H., & Ku, M.-Y. (2005). A solution to the unequal area facilities layout problem by genetic algorithm. *Computers in Industry, 56*, 207–220.

Wang, W., Rivard, H., & Zmeureanu, R. (2006). Floor shape optimization for green building design. *Advanced Engineering Informatics, 20*, 363–378.