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OPTIMIZATION OF TREE ARRANGEMENT FOR LANDSCAPE DESIGN:

PROPOSAL REGARDING TREE ARRANGEMENT PRIORITY MAPS FOR HEAT MITIGATION

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1. INTRODUCTION

1-1. *Background*

First of all, I'd like to start with an important question that many landscape designers may have; how can we arrange trees to make better use of the heat mitigation effect? Actually, although there is much knowledge about the heat mitigation effect of trees, there is very little knowledge about effectively arranging trees for mitigating heat. Therefore, we cannot answer this question clearly by referring to previous studies.

In order to answer to this question, we think that it is very effective to conduct a tree arrangement optimization. The concept of this method is shown in Fig. 1 In this method, the tree arrangement model generates a tree arrangement from some design variables such as the number of trees, crown height, and so on. Next, the thermal environment simulation calculates the heat mitigation effect using the generated tree arrangement. Then the optimization algorithm generates a design variable set of a tree arrangement considered to be superior to previous design variable sets. By repeating this cycle, we can derive the optimal tree arrangement solution.

One of the few examples using this method is the study by Chen et al. (2008). Chen conducted multiobjective optimization of tree arrangements with "minimizing SET*", "maximizing the sky factor", and "minimizing the cost of tree planting" set as the objective functions. As Chen did, we should set not only "maximizing the heat mitigation effect" but also "minimizing the cost of tree planting", as an objective function. This is because the cost of tree planting in a real design is restricted by the budget. Normally, there is a trade-off relationship between these two

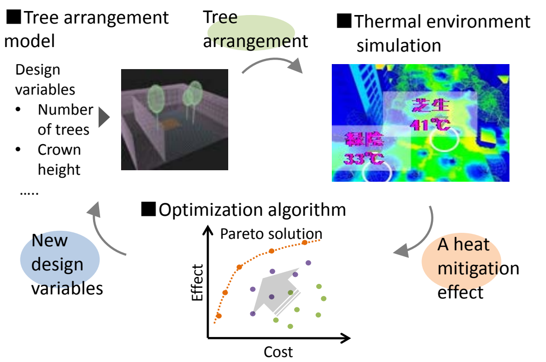

Fig. 1 Concept of tree arrangement optimization

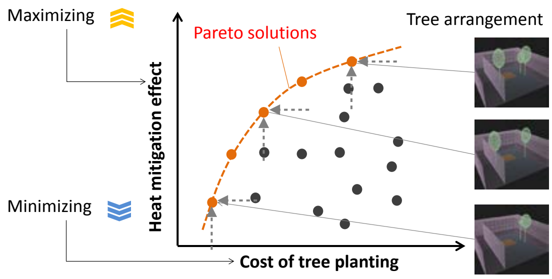

Fig. 2 Pareto solutions derived by optimization

objective functions. The optimal solution is therefore derived as Pareto solution. Each Pareto solution has a tree arrangement with a maximized heat mitigation effect and minimized cost, and judgment cannot be made as to which is superior.

1-2. *Purpose*

In order to utilize the Pareto solution for a real design flexibly, designers need to understand the concept of Pareto solutions. However, this is considered to be difficult for many designers. We thus think that the output from the optimization should be more simple and user-friendly than Pareto solutions. Therefore, we propose the "tree arrangement priority (TAP) map" that shows the location at which a tree can have a greater effect on heat mitigation (Fig. 3). Designers can design a tree

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arrangement with a great heat mitigation effect, using this map as a tool.

Therefore, the purpose of this study is to propose the "tree arrangement priority map" as more user-friendly output from the optimization, and evaluate its effectiveness.

2. METHODOLOGY

2-2. *Creation of Tree Arrange Priority Map*

Fig. 4 shows the concrete method for creating a tree arrangement priority (TAP) map.

Firstly, we conduct tree arrangement optimization and derive Pareto solutions. Secondly, by superimposing the tree arrangements of the Pareto solutions, we can get a TAP map. In this part, we consider that a location with many overlaps where a tree is arranged in many Pareto solutions is a location where a tree can have a greater effect on heat mitigation.

In addition, we defined the TAP(X) that is TAP at the position X in the area A as Expression (1).

$$TAP(X) = \frac{\sum_i^n(T_i(X))}{\max_{X\in A}\{\sum_i^n(T_i(X))\}} \quad (1)$$

$$T_i(X) = \begin{cases} 0 \left(\begin{array}{c}\text{When a tree is not arranged at} \\ \text{position "X" with Pareto solution "i"}\end{array}\right) \\ 1 \left(\begin{array}{c}\text{When a tree is arranged at} \\ \text{position "X" with Pareto solution "i"}\end{array}\right) \end{cases}$$

n: the number of Pareto solutions

$\sum_i^n(T_i(X))$ in Expression (1) is the total number of Pareto solutions in which trees are located at point X, and the overlap shown in Fig. 4 is evaluated by this. Furthermore, dividing it by $\max_{X\in A}\{\sum_i^n(T_i(X))\}$ that is the maximum value in the region in the Expression (1), TAP is standardized so that the maximum value in the entire area becomes 1.

2-2. *Calculation condition*

This part describes the specific calculation conditions used for creating a TAP map in this study. As the calculation area where the trees are arranged, we set a space surrounded by a U-shaped building and set 5 resting spots (①-⑤) in the space. As the objective functions, we set "minimizing the average

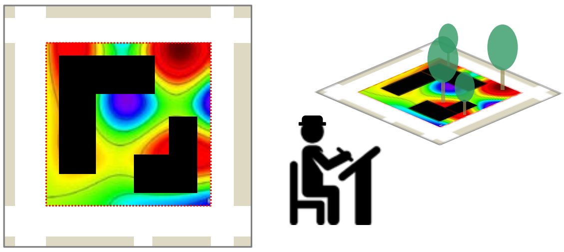

Fig. 3 Tree arrangement priority map

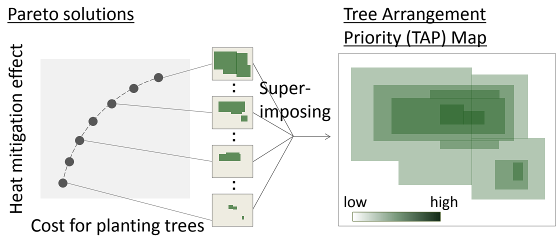

Fig. 4 Creation of a Tree Arrange Priority Map

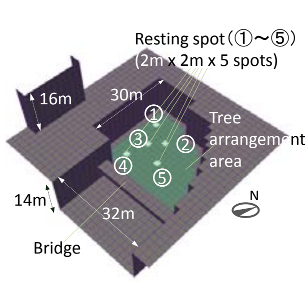

Fig. 5 Calculation area

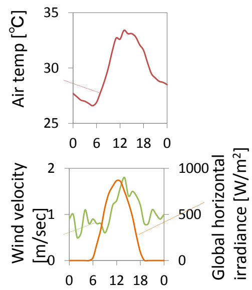

Fig. 6 Boundary condition

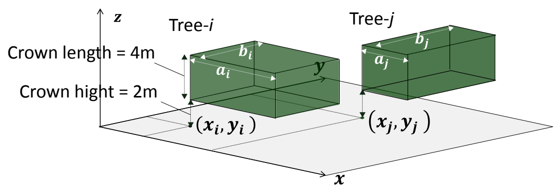

Fig. 7 Design variables of tree arrangement

MRT at the 5 resting spots" (Fig. 5). This corresponds with “maximizing the effect” mentioned above. And we set "minimizing the total tree volume". This corresponds with “minimizing the cost” mentioned above. We set up 4 cases with different times, case (a) 9 to 17, (b) 9 to 10, (c) 12 to 13, (d) 15 to 16, and calculated MRT for different times in each case. We expressed trees as rectangular parallelepipeds and the x-y-coordinates and set the x-y-size of tree crowns as design variables (Fig. 7). We fixed the crown height at 2 meters, the tree crown length at 4 meters, and the maximum number of trees at 15. Next, Fig. 6 shows the boundary conditions for calculating MRT. We selected the data measured for Tokyo on August 22nd 2010 as a sunny summer day.

2-3. *Calculation of MRT*

We calculated surface temperature by carrying out one-dimensional heat conduction calculation, and calculated the absorbed radiation of each surface mesh by the radiosity method (Catalina et al. 2008). Based on it, we calculated MRT. In the above calculation, we carried out run-up calculations for one day using the same boundary conditions. For radiative transport within foliage, we used equation (2) with reference to the model by Yoshida et al. (2006).

$$T = \exp(-kal) \tag{2}$$

l: Path length in foliage[m],
T: Transmittance at path length l[−]
k: Extinction Coeffcient[−],
a: Leaf area density[m^{-1}]

We assumed that the surface temperature of the trees is equivalent to the ambient air temperature, and we did not consider trunks.

3. RESULTS & DISCUSSION

3-1. *MRT in the absence of trees*

Fig. 8 shows the result of MRT in the absence of trees as a precondition for the optimization. Looking at the MRT in case (a) 9 - 17, each resting spot has a different MRT, and MRT tends to be higher on the east side. Looking at the other cases, the distribution of the MRT is different for each case because of the change of shadow position of the surrounding building depending on the time.

3-2. *Pareto solutions of tree arrangement*

Fig. 9 shows the result of optimization in case (a). Each plot has an MRT calculation result and total tree volume with its own tree arrangement. We can see that Pareto solutions are derived by the optimization.

Next, Fig. 10 shows the Pareto solutions and part of the tree arrangement of the Pareto solutions in each case. The MRT were calculated at different times in each case, so we can see that each case have a different MRT because of the time difference. Looking at the tree arrangement, we can see that in the solutions with a small total tree volume, trees are selectively arranged to the south of the resting spots.. On the other hand, in the solutions with a large total tree volume, trees cover all resting spots and the surrounding area. Case (a), case (b) and case (c) have similar tree arrangements, but case (d) has a different trend. This is because most of the resting spots are shaded by the building over the time of case (d) 15-16, unlike in the other cases.

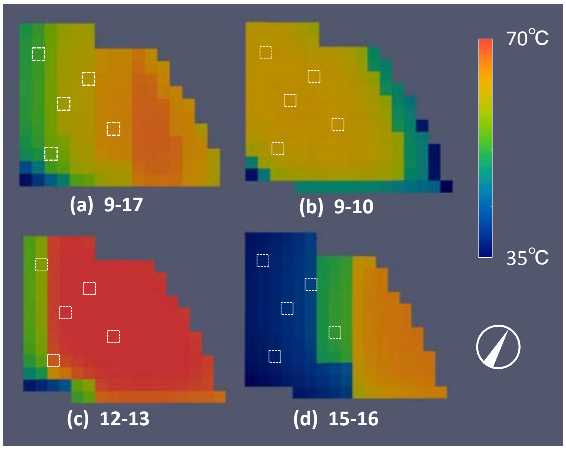

Fig. 8 MRT in the absence of trees

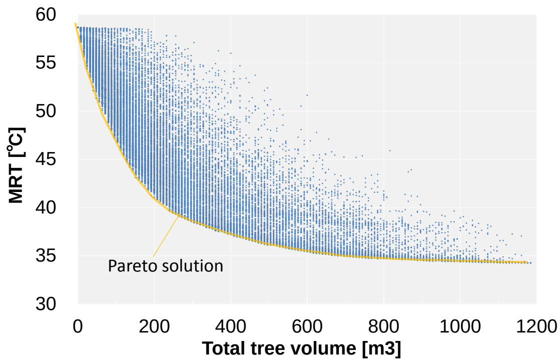

Fig. 9 Process of Optimization in Case (a)

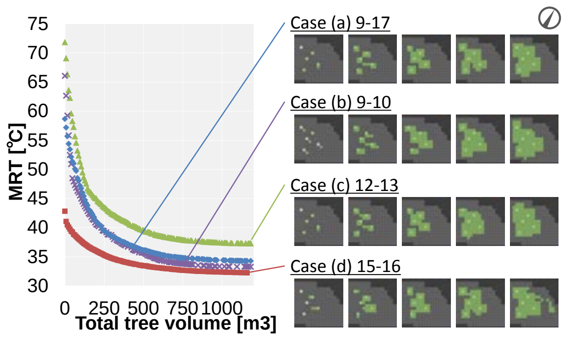

Fig. 10 Tree arrangement of Pareto Solutions of all cases

3-2. *Tree arrange priority map*

Fig. 11 shows the results for the TAP maps made by superimposing the Pareto solutions in case (a). We can see that the TAP is higher on the south side of each resting spot and the TAP is different for each resting spot. With regard to the distribution of the TAP, we can guess that the TAP would probably be higher at the positions where the MRT is higher and can largely be reduced by arranging trees. However, the TAP is highest near the central resting spot (③), where MRT is not so large (Fig. 10, Fig. 8). This is because a tree arranged near the central resting spot can reduce not only the MRT of the central resting spot but also the MRT of the surrounding resting spots. The above suggests that the TAP can evaluate "the place where trees can effectively reduce MRT", which is difficult to guess only from the calculation results of MRT.

Next, Fig. 12 shows the result for TAP maps of the other cases. Looking at case (c), the TAP is higher on the south east side of resting spot ①, while higher on the south west side of resting spot ⑤. Comparing case (b) and case (d), the TAP is higher on the south east side of resting spot ⑤ in case (b) while the TAP is higher on the south west side of the same resting spot in case (d). The position where the TAP is higher differs for each case and each resting spot. This is because the position where a tree can block sunlight effectively is different for each location and time. The above suggests that the TAP can evaluate the places where trees can reduce MRT effectively, which varies depending on the location and the time.

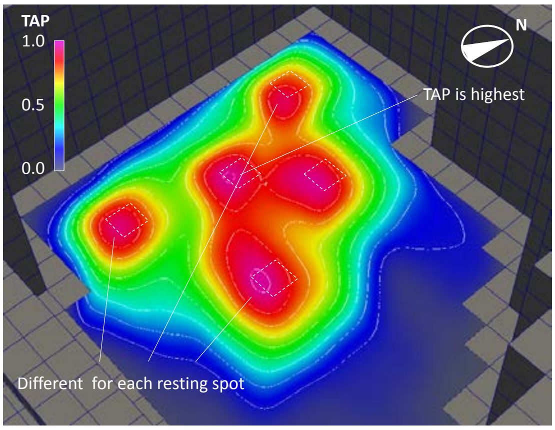

Fig. 11 Tree Arrangement Priority Map of case(a)9-17

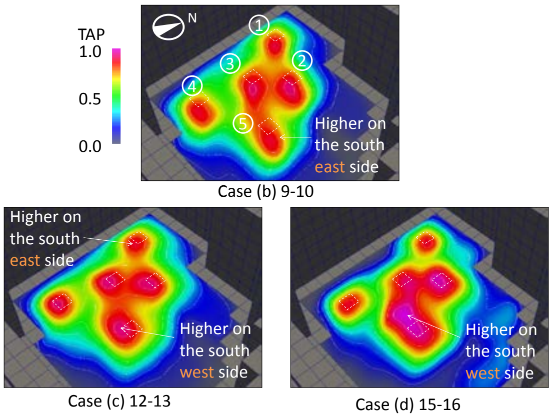

Fig. 12 Tree Arrangement Priority Map of Cases(b)-(d)

4. CONCLUSION

In order to make the output of tree arrangement optimization more user-friendly, we proposed the tree arrangement priority (TAP) map. We made TAP maps by setting concrete calculation conditions and evaluated the effectiveness of the TAP map. Based on the above, the following conclusions can be drawn:

- The distribution trends of TAP and MRT in absence of trees does not necessarily match. And it is suggested that the TAP can evaluate the magnitude of MRT reduction by arranging trees, which is difficult to guess only from calculation results of MRT.
- The distribution trend of the TAP varies depending on the location and time. And it is suggested that the TAP can evaluate the places where trees can reduce MRT effectively, which varies depending on the location and the time.

Reference

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