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STUDY ON REPRESENTING APPARENT SIZE OF ARCHITECTURAL 3D MODELS USING SPHERICAL GEOMETRY

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ABSTRACT: It is important for architectural design to confirm how each part of building can be seen from people. The cases of confirming the appearance of space with 3D models are increasing in recent years. However, it appears that the most of those works are sensory and qualitative. Therefore, in this study, the authors propose a method to quantify apparent size of architectural 3D models based on the spherical geometries and verify its efficiency.

Keywords: Gaze Vector, Apparent Size, Visible Rate, Fibonacci Lattice, Attribute Data, BIM.

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1. INTRODUCTION

It is a fundamental and important task to confirm how each part of a building can be seen from pedestrians or users in architectural and urban design. Recently, as the number of building works having a fluid space composition is increasing, the authors think that the importance to such task has increased further [Wakisaka et al. 2011]. Because, in such architecture, appearance of spaces changes drastically depending on viewpoints and the influence of the changes on use of spaces is great. Meanwhile, the cases of confirming the spatial composition by digital 3D model are increasing under the spread of BIM (Building Information Modeling) and VR (Virtua Reality) recently. Design studies using BIM or VR software are usually performed by observing 3D models with perspective or walkthrough viewing. It is considered that evaluation method in those works generally tend to be sensory and qualitative. In recent years, in response to the spread of VR research, there are research to evaluate the difference of scale sense of the physical model and VR model [e.g. Sun et al. 2013]. Though such research are important, they also reveals again how we perceive the size of architecture and urban space sensuously in the design process. On the other hand, research on the methodology for quantitatively evaluating the appearance of the space can also be seen. Isovist theory is a representative example. Isovist means a volume or area that can be seen directly from the viewpoint. As important research on the architectural space using Isovist, there are proposals on methods of calculating two-dimensional physical quantities concerning visible field and distance between viewpoints as seen in Benedikt's research [Benedikt 1979] and Turner's research [Turner et al. 2001]. In recent years, there have also been studies on spatial mutuality combining Isovist and space syntax theory [e.g. Coorey and Jupp 2013; Yamaoka et al. 2015] and studies on three-dimensional Isovist analysis method [e.g. Fukui et al. 1995; Yasuda and Monnai 2014]. These studies are interesting for quantitatively analyzing the relationship between the spatial composition and its appearance. However, they do not mention which elements are visible to what extent. On the other hand, the biggest feature of BIM is that attribute information is given to each element constituting the 3D model. Considering these together, it is assumed that applying the concept of Isovist to 3D models with attribute information makes it possible to analyze the appearance of architectural space more concretely. From the above background, the authors aim to propose the new theory for evaluating the appearance of BIM oriented architectural 3D models quantitatively. This time, we developed the method and the prototype application for quantifying apparent size of architectural 3D models as the first step. We report the details of the method and the result of a case study in this paper.

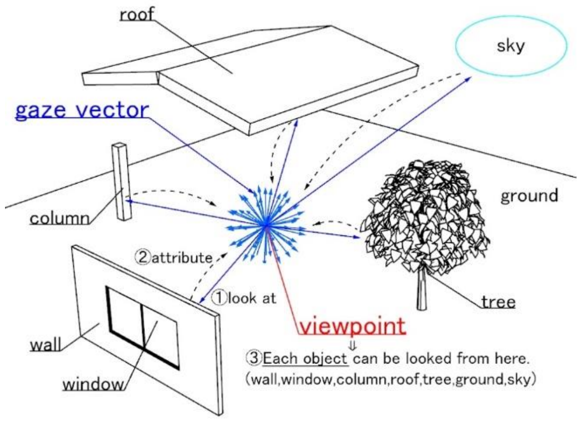


Figure 1: Conceptual image of proposed method

2. QUANTIFICATION METHOD OF APPARENT SIZE BY GAZE VECTORS

The apparent size of 3D object are often quantified as the area of 2D figure projected on a screen by perspective. In contrast, what we aim finally is modeling a new method for quantifying appearance of architectural 3D models including the distance information between a viewpoint and each object. Accordingly, we propose the method for calculating the distances to the 3D objects and their apparent sizes by using gaze vectors without perspective which eliminates the dimension of distance. Furthermore, when the designer analysis the appearance of architectural space, it is important that what he can see to what degree. For this reason, we also propose the way of extracting attribute information from the 3D model on gaze vector and counting the number of gaze vectors for each kind of attribute information (see Figure 1). In order to obtain the apparent size of 3D object using the gaze vector, the generating pattern and the number of gaze vectors are important. If many gaze vectors can be generated so that intervals between adjacent gaze vectors can be all the same, it is considered that the rate of the number of gaze vectors hitting a 3D object can be approximated to the rate of apparent size of the object. We go into the details taking wall A in Figure 2 as an example in the following.

First, the rate of a mapping area of wall A on the spherical surface to the surface area of the sphere centered on the viewpoint can be represented as the true visible rate $Rt_{(A)}$ by equation (1) .

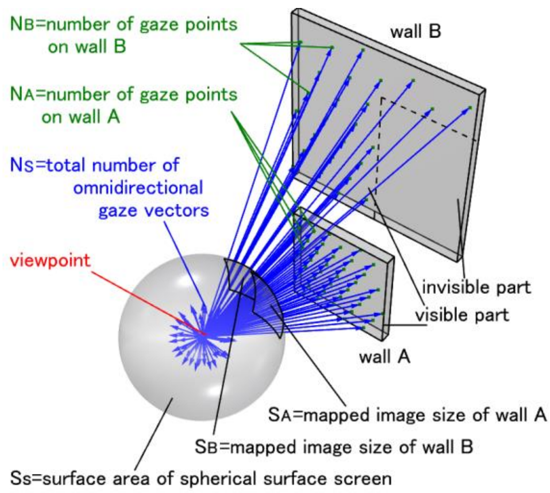


Figure 2: Theoretical image of representing apparent size of 3D objects

$$Rt_{(A)} = \frac{S_A}{S_S} \times 100\ (\%) \tag{1}$$

Then, the rate of the number of gaze vectors hitting wall A to the total number of gaze vectors generated from the viewpoint can be represented as the gaze vector visible rate $Rg_{(A)}$ by equation (2) .

$$Rg_{(A)} = \frac{N_A}{N_S} \times 100\ (\%) \tag{2}$$

Here, a difference between the true visible rate and the gaze vector visible rate on wall A can be represented as the error $E_{(A)}$ by equation (3).

$$E_{(A)} = \frac{|Rg_{(A)} - Rt_{(A)}|}{Rt_{(A)}} \times 100\ (\%) \tag{3}$$

Additionally, if intervals between adjacent gaze vectors could be uniform perfectly, it is assumed that the gaze vector visible rate Rg approach the true visible rate Rt as the number of gaze vectors increase. It can be represented by equation (4).

$$\lim_{Ns \to \infty} Rg = Rt \tag{4}$$

The method of calculating apparent size of 3D object as stated above has following two problems. The first is that the method to make the intervals between adjacent gaze vectors perfectly uniform have not been found ever. This problem can be replaced as a method of uniformly placing points on a spherical surface. There are some related research in the past [e.g. Gonzalez 2009; Keinert et al. 2015; Tanemura 1998; Yamaji 2001], but there is no established method. The second is that the computational load increases as the number of gaze vectors increases. Ideally, the gaze vector visible rate could approach true visible rate with as few number of gaze vector as possible. Therefore, it is necessary to verify to what extent number of gaze vectors is generated. From the above, in this study, we explore the efficient generating pattern and the moderate number of gaze vectors that can more accurately represent apparent size of the 3D object using the three types of gaze vector generating patterns.

3. DEVELOPMENT OF APPLICATION

We have developed a prototype application for computing apparent size 3D objects by gaze vectors using *Rhinoceros* plug-in software *Grasshopper* and *Human*. Now this application is able to support three types of generating pattern of gaze vectors, (a) latitude-longitude lattice, (b) icosahedron based lattice, and (c) Fibonacci lattice (see Figure 3). Naturally, because they all have some type of problem in terms of generating gaze vectors with uniform intervals, we implemented them to compare effectiveness at this time. The number of gaze vectors is adjustable in the application as well.

4. CASE STUDY

4.1 Outline of case study

We carried out a case study using a developed application to verify difference between three kinds of the pattern for generating gaze vectors and change of accuracy with gaze vectors increase. One of the problems about generating gaze vectors is that user cannot set number of gaze vectors one by one in (a) latitude-longitude lattice and (b) icosahedron based lattice. Therefore, we set seven cases on number of gaze vectors as shown in Table 1 and verified how close the error between the

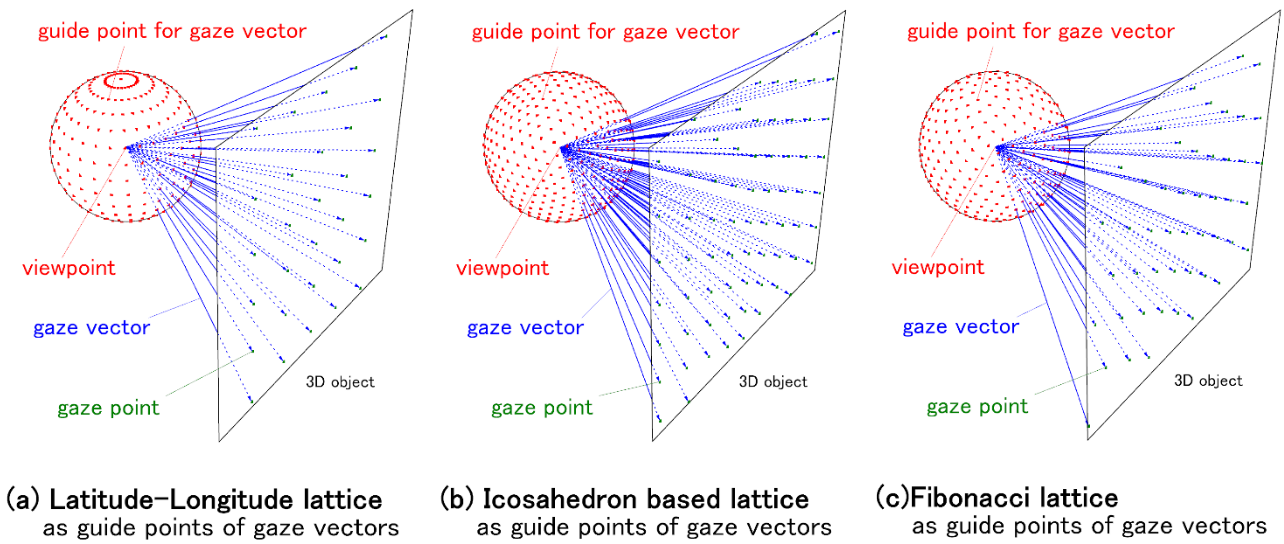


Figure 3: Three types of pattern for generating omnidirectional gaze vectors

Table 1: Total number of gaze vectors in each case of case study

Generating pattern of gaze vector	Number of gaze vectors						
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
(a) Latitude-Longitude lattice	42	146	614	2592	10256	40792	163592
(b) Icosahedron based lattice	42	162	642	2562	10242	40962	163842
(c) Fibonacci lattice	42	162	642	2562	10242	40962	163842

gaze vector visible rate and the true visible rate approach 0.

4.2 Model for case study

Figure 4 shows a 3D model for the case study. This model consists of vertical objects representing column, horizontal objects representing beams and the other objects representing walls. Every objects of columns and beams have individual names as attribute data such as A1, A'1, etc. Figure 5 shows two states of the 3D models after generating gaze vectors by Fibonacci lattice from a viewpoint located at center of the model. Green points represent gaze points where gaze vectors hit any of the objects. Even 1,000 gaze vectors seem apparently low density from the left figure. Furthermore, Figure 6 shows each state of the model after generating gaze vectors in the Case 5 of Table 1. From this, we consider that generating patterns of gaze vectors strongly affect distribution or density of gaze points on each object.

4.3 Result 1: True visible rate and gaze

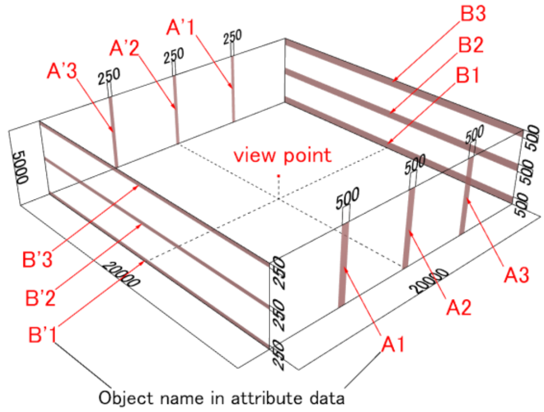


Figure 4: Objects in 3D model for case study

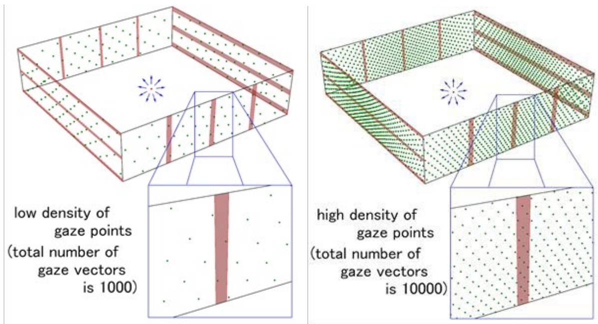
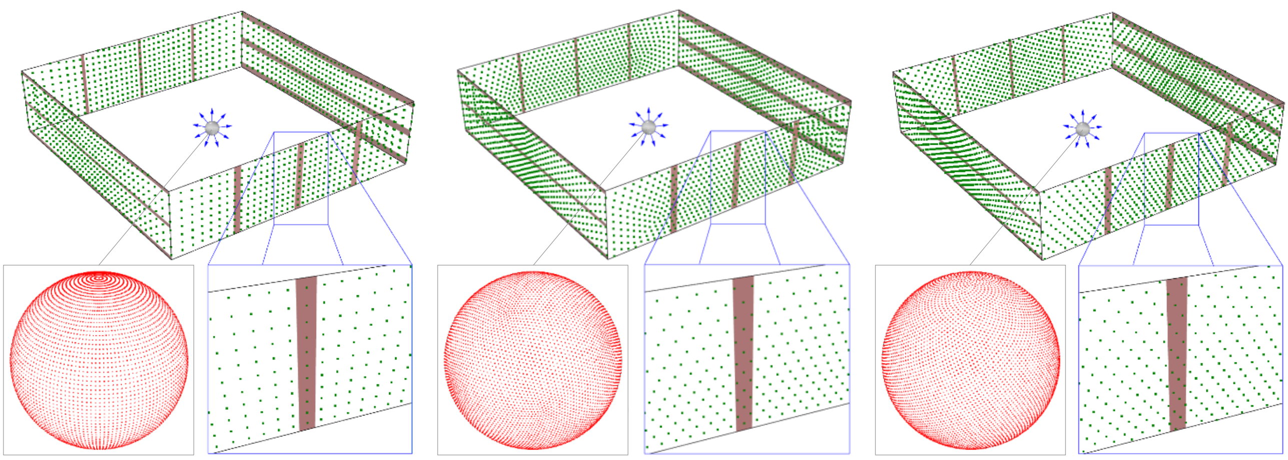


Figure 5: Samples of 3D model after generating gaze vectors by Fibonacci lattice



(a) Gaze points by latitude-longitude lattice (b) Gaze points by icosahedron based lattice (c) Gaze points by Fibonacci lattice

Figure 6: Each 3D model of (a) – (c) after generating gaze vectors in Case 5

vector visible rate

Figure 7 shows the mappings of each object on the surface of sphere centered on a viewpoint. In addition, the rightmost column of Table 2 shows the true visible rates *Rt* of each object obtained by applying the area values of each mapping to equation (1). The other columns of Table 2 shows the number of gaze vectors hit on each object and the gaze vector visible rate *Rg* obtained by applying them to equation (2) in each case of Table 1. From this data, we can find that *Rg* tend to approach *Rt* to some

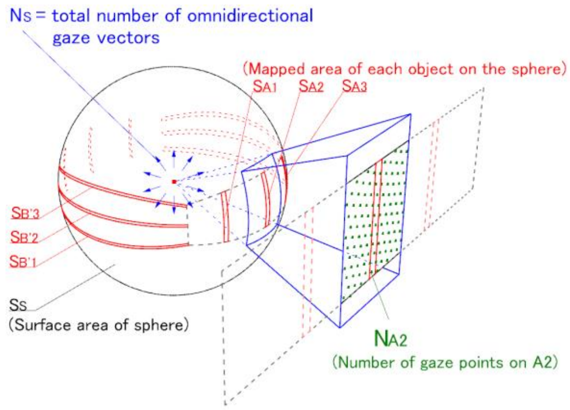


Figure 7: Mappings of each object on the surface of sphere for true visible rate

Table 2 : Number of gaze points (N) and gaze vector visible rate (Rg) in each object

Object name	Generating pattern	Case 1		Case 2		Case 3		Case 4		Case 5		Case 6		Case 7		Rt(%)
		N	Rg(%)	N	Rg(%)	N	Rg(%)	N	Rg(%)	N	Rg(%)	N	Rg(%)	N	Rg(%)	
A1	(a)	0	0	0	0	0	0	5	0.1929	11	0.1073	46	0.1128	158	0.0966	0.1377
	(b)	0	0	1	0.6173	1	0.1558	5	0.1952	14	0.1367	70	0.1709	288	0.1758	
	(c)	0	0	1	0.6173	1	0.1558	3	0.1171	15	0.1465	57	0.1392	223	0.1361	
A'1	(a)	0	0	0	0	0	0	5	0.1929	11	0.1073	46	0.1128	78	0.0477	0.0689
	(b)	0	0	1	0.6173	1	0.1558	1	0.0390	8	0.0781	34	0.0830	142	0.0867	
	(c)	0	0	0	0	1	0.1558	1	0.0390	7	0.0683	29	0.0708	112	0.0684	
A2	(a)	0	0	0	0	2	0.3257	0	0	11	0.1073	78	0.1912	220	0.1345	0.1909
	(b)	1	2.3810	1	0.6173	2	0.3115	4	0.1561	21	0.2050	72	0.1758	285	0.1739	
	(c)	0	0	0	0	1	0.1558	5	0.1952	20	0.1953	78	0.1904	312	0.1904	
A'2	(a)	0	0	0	0	2	0.3257	0	0	11	0.1073	26	0.0637	132	0.0807	0.0955
	(b)	1	2.3810	1	0.6173	2	0.3115	4	0.1561	7	0.0683	44	0.1074	145	0.0885	
	(c)	0	0	0	0	1	0.1558	2	0.0781	10	0.0976	39	0.0952	155	0.0946	
A3	(a)	0	0	0	0	0	0	5	0.1929	11	0.1073	46	0.1128	158	0.0966	0.1377
	(b)	0	0	1	0.6173	1	0.1558	5	0.1952	14	0.1367	70	0.1709	288	0.1758	
	(c)	0	0	1	0.6173	0	0	4	0.1561	14	0.1367	55	0.1343	226	0.1379	
A'3	(a)	0	0	0	0	0	0	5	0.1929	11	0.1073	46	0.1128	78	0.0477	0.0689
	(b)	0	0	1	0.6173	1	0.1558	1	0.0390	8	0.0781	34	0.0830	142	0.0867	
	(c)	0	0	0	0	0	0	3	0.1171	7	0.0683	28	0.0684	113	0.0690	
B1	(a)	0	0	0	0	0	0	15	0.5787	37	0.3608	205	0.5025	597	0.3649	0.5504
	(b)	0	0	0	0	1	0.1558	13	0.5074	52	0.5077	205	0.5005	825	0.5035	
	(c)	0	0	2	1.2346	3	0.4673	13	0.5074	58	0.5663	229	0.5591	901	0.5499	
B'1	(a)	0	0	0	0	0	0	8	0.3086	14	0.1365	101	0.2476	288	0.1760	0.2736
	(b)	0	0	0	0	1	0.1558	7	0.2732	27	0.2636	104	0.2539	413	0.2521	
	(c)	0	0	0	0	4	0.6231	7	0.2732	29	0.2831	111	0.2710	450	0.2747	
B2	(a)	0	0	0	0	0	0	0	0	37	0.3608	189	0.4633	603	0.3686	0.5564
	(b)	0	0	0	0	6	0.9346	11	0.4294	51	0.4979	202	0.4931	821	0.5011	
	(c)	0	0	1	0.6173	5	0.7788	15	0.5855	58	0.5663	224	0.5468	913	0.5572	
B'2	(a)	0	0	0	0	0	0	0	0	31	0.3023	101	0.2476	298	0.1822	0.2782
	(b)	0	0	0	0	6	0.9346	10	0.3903	26	0.2539	103	0.2515	414	0.2527	
	(c)	1	2.3810	0	0	2	0.3115	9	0.3513	26	0.2539	112	0.2734	456	0.2783	
B3	(a)	1	2.3810	0	0	0	0	13	0.5015	37	0.3608	193	0.4731	540	0.3301	0.4990
	(b)	0	0	1	0.6173	3	0.4673	11	0.4294	49	0.4784	206	0.5029	821	0.5011	
	(c)	1	2.3810	0	0	6	0.9346	13	0.5074	50	0.4882	206	0.5029	826	0.5041	
B'3	(a)	1	2.3810	0	0	0	0	6	0.2315	12	0.1170	93	0.2280	268	0.1638	0.2470
	(b)	0	0	0	0	0	0	4	0.1561	26	0.2539	105	0.2563	409	0.2496	
	(c)	0	0	1	0.6173	0	0	8	0.3123	26	0.2539	102	0.2490	402	0.2454	

extent in any of objects as the number of gaze vectors increase. The strong tendency can be found in the case of (c) Fibonacci lattice especially. In contrast, the tendency is weak in (a) latitude-longitude lattice.

4.4 Result 2: Error between true visible rate and gaze vector visible rate

Table 3 shows errors between the gaze vector visible rate Rg and the true visible rate Rt in Table 2 using equation (3). The bottom 3 lines in Table 3 shows averages of errors of all objects in each of cases. Figure 8 is a graph on them. As the result of comparing three types of generating patterns of gaze vectors, (c) Fibonacci lattice has the lowest error and also certainly diminish as the number of gaze vectors increase. In addition, from the data of 1.27% in case 6 and 0.48% in case 7 in the same pattern, we infer that the error can be less than 1% by generating 100,000 gaze vectors with (c) Fibonacci lattice.

5. CONSIDERATION

Through this case study, we confirmed that the approach of gaze vector visible rate using Fibonacci lattice is considerably efficient as the method for quantifying apparent size of 3D model represent an architectural space. The 3D model used in case study has the scale of 20 meters square, and includes some objects the size is 250mm or 500mm. Therefore, unless the model keeps near dimensional relation relatively, this method will be usable for various analysis. However, if we calculate using another model that have slenderer objects and larger space than the present model, there is also possibility that the density of gaze vectors is deficient and it is not so effective. In that case, though increasing number of gaze vectors may be effective, the calculation will take more time. The number of polygons of the 3D model in this time is very small; nevertheless it took about 5 minutes each to finish calculation in Case 7. Since the actual architecture or urban model is much more complicated than this model, it is better not to generate too many gaze vectors in order to

Table 3: Error of gaze vector visible rate

Object name	Generating pattern	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
		E(%)	E(%)	E(%)	E(%)	E(%)	E(%)	E(%)
A1	(a)	-	-	-	28.60	28.41	22.13	42.60
	(b)	-	77.69	11.58	29.43	0.75	19.41	21.65
	(c)	-	77.69	11.58	17.62	5.96	1.03	1.19
A'1	(a)	-	-	-	64.30	35.80	38.93	44.43
	(b)	-	88.84	55.79	76.42	11.84	17.04	20.55
	(c)	-	-	55.79	76.42	0.75	2.73	0.74
A2	(a)	-	-	41.39	-	78.01	0.15	41.97
	(b)	91.98	69.07	38.71	22.29	6.88	8.62	9.76
	(c)	-	-	22.57	2.17	2.23	0.26	0.26
A'2	(a)	-	-	70.69	-	10.98	49.81	18.33
	(b)	95.99	84.53	69.35	38.84	39.70	11.11	7.89
	(c)	-	-	38.70	22.31	2.21	0.29	0.93
A3	(a)	-	-	-	28.60	28.41	22.13	42.60
	(b)	-	77.69	11.58	29.43	0.75	19.41	21.65
	(c)	-	77.69	-	11.79	0.75	2.57	0.16
A'3	(a)	-	-	-	64.30	35.80	38.93	44.43
	(b)	-	88.84	55.79	76.42	11.84	17.04	20.55
	(c)	-	-	-	41.19	0.75	0.74	0.16
B1	(a)	-	-	-	4.89	52.56	9.52	50.82
	(b)	-	-	253.34	8.47	8.40	9.97	9.30
	(c)	-	55.42	17.78	8.47	2.81	1.55	0.08
B'1	(a)	-	-	-	11.34	100.45	10.51	55.43
	(b)	-	-	75.67	0.15	3.80	7.77	8.55
	(c)	-	-	56.08	0.15	3.36	0.98	0.37
B2	(a)	-	-	-	-	54.22	20.08	50.94
	(b)	-	-	40.47	29.58	11.73	12.82	11.03
	(c)	-	9.87	28.56	4.97	1.75	1.74	0.16
B'2	(a)	-	-	-	-	7.95	12.37	52.74
	(b)	-	-	70.23	28.72	9.60	10.65	10.11
	(c)	88.31	-	10.69	20.80	9.60	1.76	0.03
B3	(a)	79.04	-	-	0.50	38.32	5.47	51.18
	(b)	-	19.16	6.79	16.23	4.31	0.77	0.41
	(c)	79.04	-	46.60	1.65	2.22	0.77	1.02
B'3	(a)	89.62	-	-	6.72	111.13	8.35	50.79
	(b)	-	-	-	58.22	2.69	3.63	1.04
	(c)	-	59.98	-	20.89	2.69	0.79	0.68
Avg.	(a)	84.33	-	56.04	26.16	48.50	19.87	45.52
	(b)	93.99	72.26	62.66	34.52	9.36	11.52	11.87
	(c)	83.68	56.13	32.04	19.04	2.93	1.27	0.48

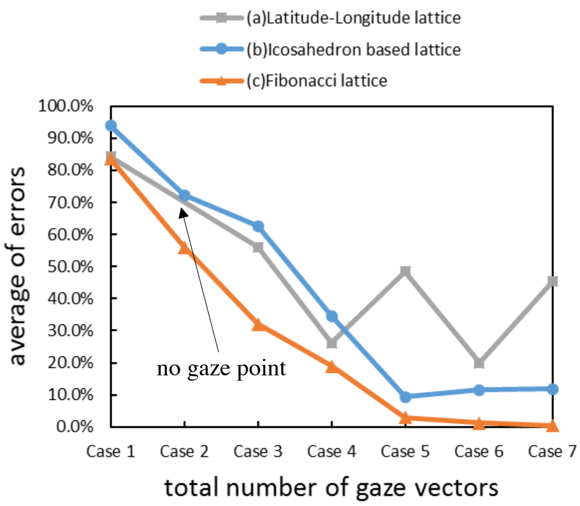


Figure 8: Relationship between total number of gaze vectors and error

keep calculation time short. It is important to select the number of gaze vectors suitable for the size of the whole model and the size of the smallest object.

6. CONCLUSION

In this study, we proposed the visible rate using gaze vectors as a method to quantitatively confirm the apparent size of architectural space and verified its effectiveness through case study. As a result, it is clarified that the gaze vector visible rate using Fibonacci lattice is effective. In the developed application, since the number of gaze vectors hitting the object can be counted for each type of attribute information, various analysis according to the purpose can be considered by devising how to give attribute information. As a future task, it is necessary to clarify the use purpose of the proposed method, and to optimize the functionality and algorithms for that purpose. In addition, this time we did not take into consideration the human field of vision, but we need to take that into account at the next stage.

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