THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

Suitable Size of 3D Printing Architecture Models for Tactile Exploration

Tetsuya Watanabe, Kana Sato

Faculty of Engineering, University of Niigata, Ikarashi

t2.nabe@eng.niigata-u.ac.jp

Abstract

Three-dimensional (3D) printers are useful in the education and welfare of the blind. However, there are not any established guidelines on the suitable size of models produced by 3D printers. We, therefore, printed models of six famous architectures with different complexities in three sizes (6, 12, and 18 cm). We conducted an experiment in which participants tactually explored these models, answered questions on the physical features of the architectures, and evaluated each model. The results of the physical feature questionnaires showed difficulty in detecting small dots (a few millimeters wide) in the 6-cm models and dented structures in all model sizes, and showed different impressions given by different sizes. The 18-cm models gained the highest ratings for all architectures but even smaller-sized models of less complicated architectures were understandable.

Keywords

3D Printer, Blind and Visually Impaired People, Tactile Exploration, Architectural Model

Introduction

For blind and visually impaired people to understand the shapes of objects, a touch is worth a thousand words. When objects are too large, too small, dangerous, or fragile to touch, scale models are used instead. These days, three-dimensional (3D) printers have been playing a major role in producing such models. Most examples of how 3D printers can be applied to blind people can be found in education (astronomy (Grice et al, 2015), biology (Kolitsky, 2014), literacy (I et al, 2016)) and maps (Gual et al, 2015, Holloway, 2018).

We decided to focus on architectural models after a blind certified architect requested us to print models of famous architectural buildings with a 3D printer. While printing them, we wondered what size would be suitable for tactile exploration. If the models are too small, people would not be able to fully understand their shapes through touch. Contrastingly, if the models are too large, holding and exploring the whole surface of them would be a burden. Therefore, we hypothesized that there is a suitable size for tactile exploration. To verify this hypothesis, we conducted an experiment in which three sizes of six architecture models were presented to ten blind and visually impaired participants and evaluated.

3D Printing

Selection of Architectures

We chose six architectures from the World Heritage list. They are the El Castillo, Castel del Monte, Taj Mahal, Sydney Opera House, St. Basil’s Cathedral, and Angkor Watt. They were classified into three complexity levels, I: simple, II: middle, and III: complex, on the basis of structural characteristics. The locations (country) and complexity levels of the selected architectures are listed in Table 1.

Table 1. Selected Architectures.

Complexity Level	Architecture	Location (Country)
I	El Castillo	Mexico
I	Castel del Monte	Italy
II	Taj Mahal	India
II	Sydney Opera House	Australia
III	St. Basil's Cathedral	Russia
III	Angkor Watt	Cambodia

Printing

We used an FDM 3D printer, DaVinci 1.0 (XYZ printing), and ABS filament. The maximum size for a printed object available with this printer is H 20 cm x W 20 cm x D 20 cm (7.9"). As this printer can read standard STL files, the architectures in this format were downloaded from Thingiverse (https://www.thingiverse.com/). To resolve any errors, Netfabb Studio Basic ver.4.9.5 (AUTODESK) was used. To change the size of the models, Tinkercad (https://www.tinkercad.com) was used. To split the model into two parts, we used 3D Builder ver.15.1 (Microsoft Corporation).

The six architecture models were printed in three sizes: 6 cm (2.4"), 12 cm (4.7"), and 18 cm (7.1"). These were the longest side among the height, width, and depth of each architecture. Fig. 1 shows the 12-cm models of the six architectures.

Experiment

In the experiment, we had the blind and visually impaired participants tactually explore different sizes of 3D-printed architectural models. The correct rate and subjective evaluation were used as evaluation criteria.

The participants were ten blind and visually impaired people, nine men and one woman. The age range was from 34 to 68 years old with the average of being 63.5.

Eighteen architectural models (six architectures x three sizes) were used as the stimuli.

The experiment consisted of the comprehension test session and subjective evaluation session. In the test session, six architectural models were presented in one of the three sizes. The procedure of the test session was as follows.

(1) The participant explored a model tactually for five minutes.
(2) After the exploration, the experimenter orally gave six questions on the structural characteristics: the number, arrangement, size, and shape of some parts of the architecture. The participants were asked to answer to these questions orally or by pointing at the specific part of the model. The maximum answering time was two minutes. While answering, the participant was allowed to touch the model again.

The models of the three sizes were then evaluated subjectively. The procedure of the evaluation session was as follows.

(1) All three sizes of an architecture model were presented to the participant at the same time.
(2) The participant was asked to place them in order of comprehensiveness.
(3) Given that the most comprehensive size model would score ten points, the participant was required to score the other two sized models as between one and nine points.

This procedure was repeated six times.

This experiment was reviewed by the Ethics Committee of Niigata University and conducted with the permission of the President (permission number: 2017-0148).

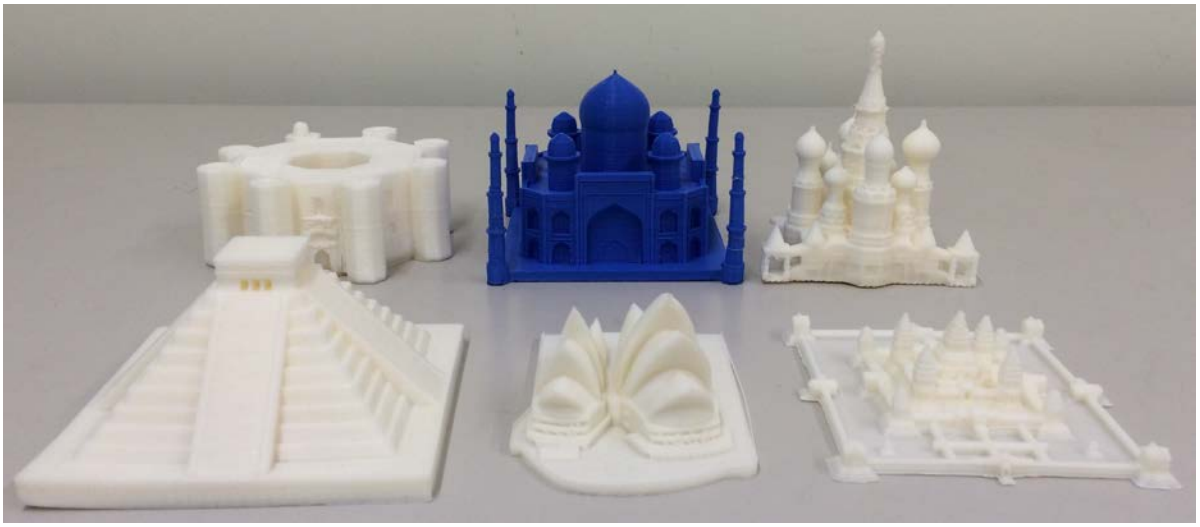

Fig.1. 12-cm Models of Six Architectures.

Results

Size Effect on Correct Rate

Fig. 2 shows the size effect on the correct rate for the questions on structural characteristics of each architecture. For the 18-cm models, five out of six architectures gained relatively high correct rates, ranging from 67 to 88%. For the 12-cm models, the correct rates were lower by 5% on average. For the 6-cm models, the correct rates varied from 44 to 88% depending on architecture. As the relationship between the size and correct rate changed depending on architecture, we used nonparametric Kruskal-Wallis tests for each architecture. However, they did not show any significant difference in the correct rate among the three sizes for all architectures (H = 3.20, 2.69, 0.94, 1.86, 2.14, 0.07. The order of the architectures is the same as those shown in Table 1.).

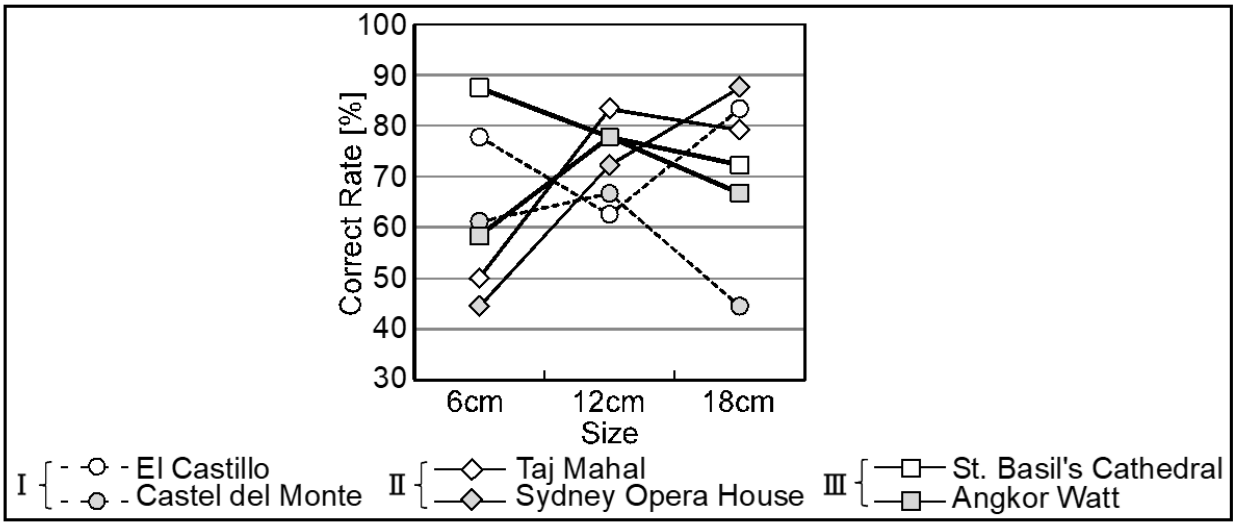

Fig. 2. Size Effect on Correct Rate.

Subjective Evaluation

Subjective ratings averaged over ten participants for each architecture and each size are shown in Fig. 3. In all architectures, the 18-cm models gained the highest average ratings, with the ratings decreasing with the subsequent smaller models. We used a nonparametric Friedman test for each architecture and found significant differences in the subjective rating among the three sizes for all architectures (S = 16.8, 15.8, 12.6, 20.0, 20.0, 18.2, $p < 0.01$. The order of the architectures is the same as those shown in Table 1.). For pairwise comparison tests, the Wilcoxon signed-rank test was repeatedly used. The tests showed significant differences between every pair of the three size conditions.

In Fig. 3, the effect of complexity level was observed as well. Seven out of the ten participants rated all 18-cm models as the most comprehensive (10 points). The other three participants rated five of the 12-cm models with a complexity level of I and II as the most comprehensive and the other with a complexity level of III. Some participants commented that the structural characteristics of simple architectures could be understood even with the 12-cm models. For the 6-cm models, the ratings of four architecture models with the lowest and middle complexity level (I and II) were not as low as those of the two architecture models with the highest complexity level (III).

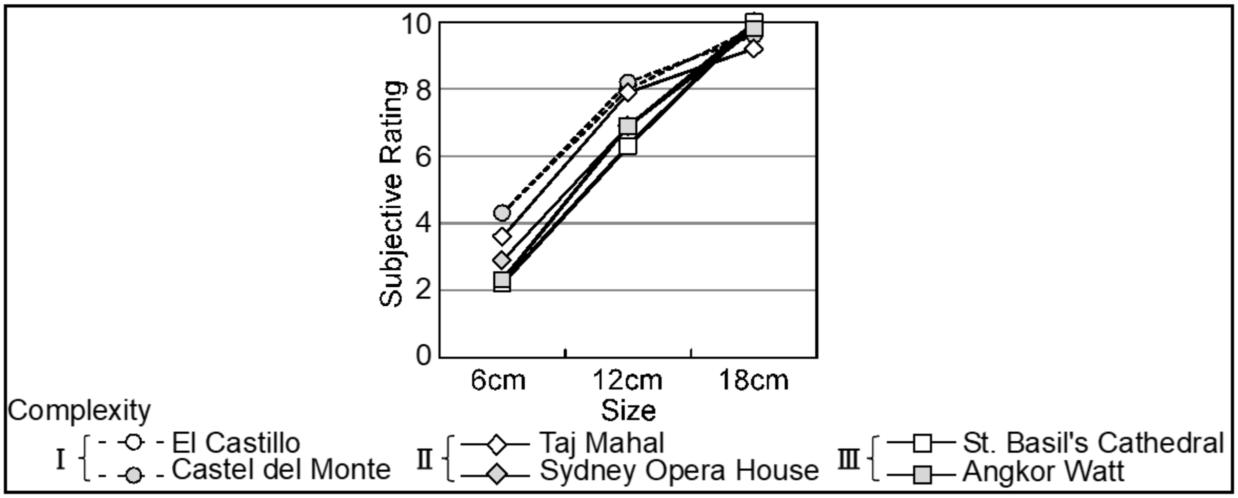

Fig.3. Size Effect on Subjective Evaluation.

Discussion

In this section, we examine the individual combinations of architecture and question that led to the lower correct rates, roughly 60% or lower. The 6-cm models often presented issues classed as “too small to detect” (ex. the pedestals in the facade of El Castillo were not found), “hard to detect concaves” (ex. fingers could not go through the spaces between the cloisters of Angkor Watt), and “feeling different from what they represent” (ex. the four towers around the main tower of the Taj Mahal were not perceived as “domes,” and the small projections of the Sydney Opera House were not perceived as “roofs”). Contrarily, a small projection was unintentionally perceived as a “dome” in the 18-cm model of the Castel del Monte, and this misinterpretation caused a lower correct rate. These phenomena that the same shape but different size gave the participants different impressions were worth noticing.

Conclusion

We conducted an experiment in which three different-sized architectural models were presented to blind and visually impaired subjects and measured the comprehensiveness and subjective rating of each model. In the comprehension test, the smallest 6-cm model often presented a few problems with undetectable objects, undetectable concaves, and feeling different from what they present. This “feeling different” problem was also observed in the 18-cm model of one particular architecture. In contrast, the subjective rating clearly showed the superiority of bigger models. The subjective rating also shows the effect of complexity: simple architectures were comprehensible enough with middle- or small-sized models. At present, it is not clear whether models that are bigger than 18-cm can be evaluated as being more comprehensive or too big to explore by touch. The consideration of other practical factors, such as maximum printable size with reasonable-priced 3D printers, time to print, cost of materials, storage space, etc., may help determine how big the models need to be.

Acknowledgements

This study was supported by JSPS KAKENHI Grant Numbers JP25245084 and JP17H02005. We thank all the participants for their cooperation.

Works Cited

Gual, J., Puyuelo, M., & Lloveras, J. (2015). The Effect of Volumetric (3D) Tactile Symbols within Inclusive Tactile Maps. Applied Ergonomics, 48, 1-10.

Grice, N., Christian, C., Nota, A., & Greenfield, P. (2015). 3D Printing Technology: A Unique Way of Making Hubble Space Telescope Images Accessible to Non-Visual Learners. Journal of Blindness Innovation and Research, 5(1).

Holloway, L., Marriott, K. & Butler, M. (2018). Accessible Maps for the Blind: Comparing 3D Printed Models with Tactile Graphics, CHI '18 Proc. of the 2018 CHI Conference on Human Factors in Computing Systems, Paper No. 198.

I, J. H., Harianto, R. A., Chen, E., Lim, Y. S., Jo, W., Moon, M.-W., & Lee, H. J. (2016). 3D Literacy Aids Introduced in Classroom for Blind and Visually Impaired Students. Journal of Blindness Innovation and Research, 6(2).

Kolitsky, M. A. (2014). 3D Printed Tactile Learning Objects: Proof of Concept. Journal of Blindness Innovation and Research, 4(1).