The Effect of Complex Wall Forms on the Room Acoustics

An experimental case study

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The complexity of the wall form affects the acoustics of the space. In this study, the effect of the complex form walls produced by nCloth dynamic simulation on the acoustics of an office space was investigated. In this research, reverberation time and Speech Transmission Index (STI) values of the pilot office space with one wall having complex form and the office space with all of the walls as flat were measured by acoustic simulation. As a result of the comparison, it has been found that, within speech intelligibility and reverberation time, the acoustics of the space with one wall having complex form is better than the acoustics of the space with all the walls as flat.

Keywords: *nCloth, Acoustics, Complex forms, Modeling & simulation*

INTRODUCTION

Form production in complex morphologies is a very contemporary issue in today's architectural world. With the widespread use of robotic fabrication, research has accelerated in this regard. In the near future robotic fabrication will become even more widespread and it can be assumed that such productions will be more economical. There is a search for methods to be followed in forming such morphologies. Researches of Kohler et. al (2014) and Braumann and Brell-Cokcan (2012) on complex wall morphology are examples of the work in this area.

As Reinhardt et al (2014) and Reinhardt et al (2017) said, acoustic can be improved with complex curved spaces. The hypothesis of this study is that the acoustics of the space created by using complex forms are better than the acoustics of the space created by flat walls in the context of spaces for speech. In this study, this hypothesis was intended to be quantitatively tested in an experimental case study. In this study, an office space created with flat walls and an office space with a wall of complex form were compared in terms of reverberation values (in different frequency bands) and Speech Transmission Index (STI) values.

Reverberation time (RT) is an important criterion for understanding the acoustics of the room (Kuttruff, 2000). Reverberation time depends on the surface area, material absorption coefficients and volume of the space (Peters, 2009). As the time of reverberation increases, the speech in the room becomes less understandable. So it is not preferred to have a very long reverberation time in the room for speech. As seen in the graph of Barron (2010)'s book, the value of general recommended reverberation time for speech is 1 (Figure 1).

The speech intelligibility of the room is another criterion for understanding the acoustics of the room.

The Speech Transmission Index (STI) can be used to measure speech intelligibility in the room. The value of the range of STI is between 0 and 1.

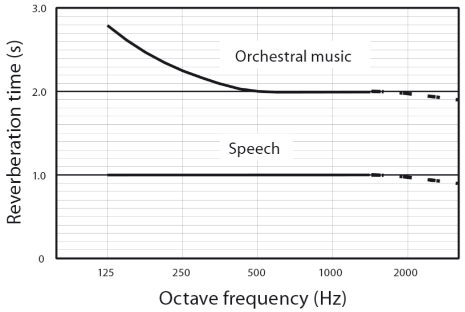

Figure 1
General recommended reverberation time for speech and orchestral music (Barron, 2010)

The best speech intelligibility is 1, while the worst speech intelligibility value is 0 (Yavuz et. al. 2018).

Greg Lynn (1999) has introduced a new perspective on the design process, bringing out the issue of designing with animation. In this work, designing with animation / simulation is defined as a methodology for creating complex wall morphology. Various form productions were performed using nCloth simulation. In this study, with this complex form production method, nCloth simulation, which is a form morphogenesis process with rules, and acoustic relationship was examined, unlike the forms in the studies (Bonwetsch, 2008; Peters, 2009; Peters and Olesen, 2010; Reinhardt et.al 2017; Skov et. al. 2017) investigating the relationship between acoustic and the other complex geometries.

nCloth is a dynamic simulation produced for character clothing in character animation. This simulation is used extensively in film and animation industry. In the field of architecture, it is thought that this simulation can be used for complex form formations, because this simulation allows various types of forms to be produced within the specified time period by adjusting various parameters (Agirbas and Ardaman, 2016; Agirbas and Ardaman, 2017; Agirbas, 2018).

METHODOLOGY

In this study, Autodesk Maya, Rhino and Pachyderm programs were used. The Pachyderm program works as a plug-in to Rhino [1,2[. And it should be noted that this program is in the experimental stage [3]. In Maya, form experiments were performed using nCloth simulation as a dynamic simulation. Simulations were performed using various presets of nCloth simulation (such as lava, waterbaloon). In addition, various objects have been determined as colliders for differentiating form production. Thus, the nCloth object can be shaped according to a certain collider. These simulations were stopped at various time frames and form formations were observed. Then, the fabrication of the forms was made using CNC (Figure 2, Figure 3).

Then, the complex form produced by nCloth simulation with using the lava preset was considered as a wall of a room. To do this, first, the simulation was stopped at different frames. The forms formed in these stopped frames were transferred to the Rhino platform. In Rhino, a room with a floor area of 15 meters to 10 meters was modeled and the form formed at 30th frame of the nCloth simulation was placed on a long wall of the room. Another long wall of the room was designated as a window. This room was thought to be an office room and tables were placed inside the room. Prior to the acoustic analysis in Pachyderm program, which works as a plug-in for Rhino, a variety of materials, which were defined in Pachyderm program together with the material absorption coefficient values, were assigned for these tables, floor, ceiling, carpet, cubical, walls and window (Table 1). Also, a receiver and a source were defined in the room (Figure 4). Then, T30 (reverberation time in 30 dB), T15 (reverberation time in 15 dB) and STI values were found as a result of acoustic simulation.

Then, in order to test the hypothesis of this study, an acoustic simulation was performed for a room of the same size and material having 4 flat walls. In addition, acoustic simulations were done for the same room by using the forms formed in different frames

Figure 2
Wall formations via nCloth simulation with different presets (These prototypes was produced by students in the course which was given by the author)

(60th, 90th, 240th and 390th frames) of the nCloth simulation.

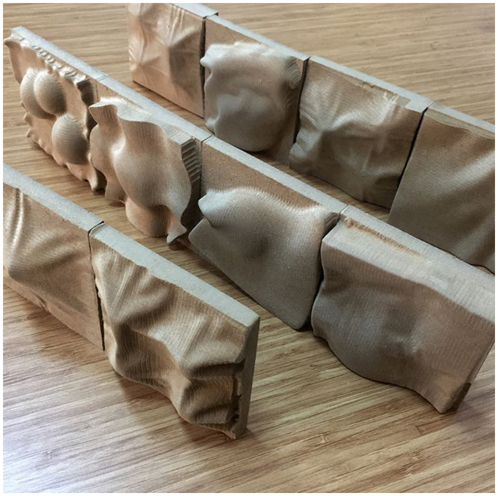

Figure 3
Complex form prototypes (These prototypes was produced by students in the course which was given by the author)

RESULTS

- According to the results of the simulation, it was found that the reverberation values of the room having one wall formed by nCloth (complex form) were lower than the reverberation values of the room formed by the flat walls (Table 2). This result confirms the hypothesis of this study. For example, in the space with one complex formed wall created by nCloth simulation stopped at frame 30, the reverberation time (T30) is 0.75 for 250 Hz, the reverberation time (T30) is 0.95 for 500 Hz and the reverberation time (T30) is 0.96 for 1000 Hz, while, in the space with all flat walls, the reverberation time (T30) is 1.28 for the 250 Hz, the reverberation time (T30) is 1.79 for the 500 Hz and the reverberation time (T30) is 1.94 for the 1000 Hz.
- In addition, acoustic simulations were done for the same room by using the forms formed in different frames of the nCloth simulation. According to the results of these simulations, reverberation values of the room formed by flat walls were found to be more than the reverberation values of the rooms formed with other forms. In the space with all flat walls, the reverberation time (T30) is 1.28 for the 250 Hz, while, in the space with one complex formed wall created by nCloth simulation stopped at frame 30, the reverberation time (T30) is 0.75 for 250 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 60, the reverberation time (T30) is 0.89 for 250 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 90, the reverberation time (T30) is 0.67 for 250 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 240, the reverberation time (T30) is 1.19 for 250 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 390, the reverberation time (T30) is 0.87 for 250 Hz. The other example, in the space with all flat walls, the reverberation time (T30) is 1.79

for the 500 Hz, while, in the space with one complex formed wall created by nCloth simulation stopped at frame 30, the reverberation time (T30) is 0.95 for 500 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 60, the reverberation time (T30) is 1.26 for 500 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 90, the reverberation time (T30) is 0.98 for 500 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 240, the reverberation time (T30) is 1.49 for 500 Hz; in the space with one complex formed wall created by nCloth simulation stopped at frame 390, the reverberation time (T30) is 1.34 for 500 Hz. However, it seems from the results that any correlation was not found between the reverberation values of the rooms formed with other forms (Table 2).

Table 1
Material Absorption Values in Pachyderm

Material Absorption (% energy absorbed)	62.5 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
ACT	18	56	76	59	63	76	87	94
Glass	37	27	17	10	7	7	7	7
Wall	24	19	11	5	5	5	5	5
Carpet	11	11	14	19	31	33	36	31
Desks	15	10	5	5	5	5	5	5
Cubical	40	40	40	40	40	40	40	40

- The STI value of the room formed by flat walls was found to be 0.55, while the STI values of the rooms having one wall with complex form were found to be higher (These values are calculated with Noise Rating: 40). For example, for the space with one complex formed wall created by nCloth simulation stopped at

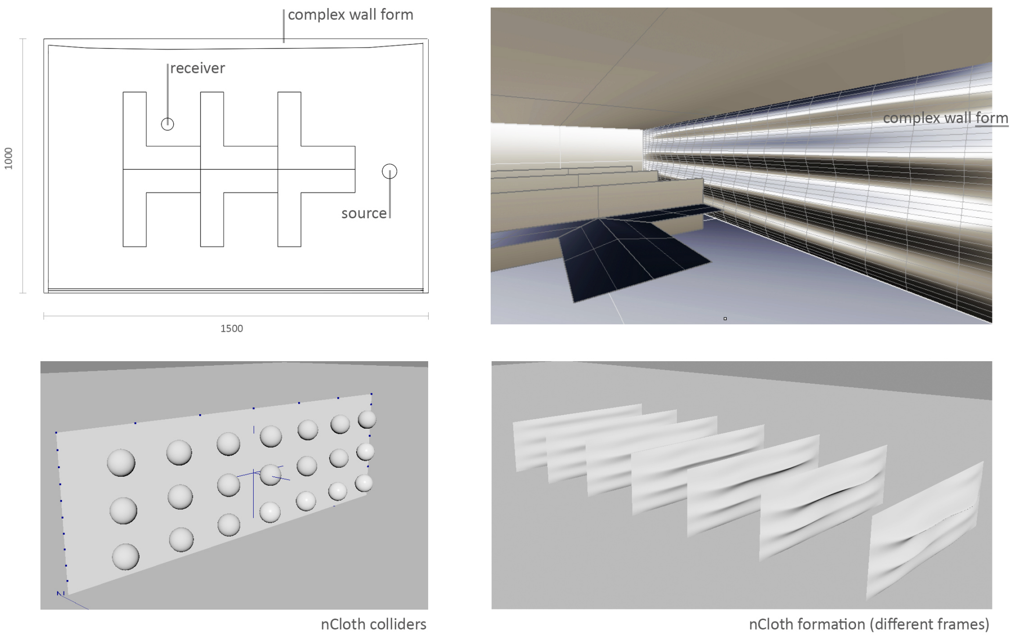

Figure 4
nCloth formation and its replacement to the sample room model

Table 2
Reverberation times of the spaces with different wall forms

			62.5 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Form as simple box		T15(s)	0.69	0.72	1.03	1.58	1.73	1.72	1.68	1.43
		T30(s)	0.72	0.86	1.28	1.79	1.94	1.97	1.88	1.76
Form with nCloth	Frame 30	T15(s)	0.67	0.54	0.56	0.74	0.75	0.68	0.55	0.42
		T30(s)	0.70	0.66	0.75	0.95	0.96	0.95	0.93	0.79
	Frame 60	T15(s)	0.67	0.54	0.54	0.77	0.74	0.69	0.64	0.53
		T30(s)	0.72	0.72	0.89	1.26	1.23	1.34	1.52	1.19
	Frame 90	T15(s)	0.66	0.54	0.55	0.67	0.66	0.61	0.56	0.53
		T30(s)	0.70	0.59	0.67	0.98	1.00	0.99	1.00	0.79
	Frame 240	T15(s)	0.67	0.58	0.65	0.79	0.82	0.82	0.81	0.76
		T30(s)	0.68	0.70	1.19	1.49	1.64	1.78	1.73	1.51
	Frame 390	T15(s)	0.67	0.58	0.63	0.82	0.78	0.78	0.72	0.69
		T30(s)	0.68	0.63	0.87	1.34	1.40	1.52	1.52	1.46

frame 30, STI value is 0.62; for the space with one complex formed wall created by nCloth simulation stopped at frame 60, STI value is 0.63; for the space with one complex formed wall created by nCloth simulation stopped at frame 90, STI value is 0.61; for the space with one complex formed wall created by nCloth simulation stopped at frame 240, STI value is 0.62 and for the space with one complex formed wall created by nCloth simulation stopped at frame 390, STI value is 0.63 (Table 3). In other words, speech intelligibility of the rooms having the complex form walls is better. This confirms the hypothesis of this study.

- The walls also function as furniture, and integrated designs can be obtained. Thus, the walls directly influence the space organization. The creation of living spaces is becoming one stage, thus some sort of ergonomics is achieved.
- Various technical elements can also be hidden in such walls. It is possible to obtain more volume of the interior space by using the minimum volume in some parts of the walls (because of the complex form).
- With the production of such walls, the architect satisfies his aesthetic understanding.
- The production of these types of complex walls by digital fabrication leads to the search of new materials. This search also directs the scientific community to the creation of new types of composite materials, and encourages the production of them.

Table 3
Speech Transmission Index of the spaces with different wall forms

	STI (NR:40)
Form as simple box	0.55
Frame 30	0.62
Frame 60	0.63
Frame 90	0.61
Frame 240	0.62
Frame 390	0.63

CONCLUSION

It has been seen that complex shaped walls help to have shorter reverberation time in space and to have better speech intelligibility. In this study, the experimental study was done through an office space. This kind of experiments for spaces with other functions will be important in terms of examining the relationship between complex form - function of space -acoustics - material. These parameters should not be considered separately.

Nowadays, because of the changing design process with technological facilities, many different parameters can be thought together at the early stage of the design. Even with optimization algorithms, the best solution can be determined in the early design process. So, the next step in this work can be to optimize the shape of the room or the walls of the room, depending on the desired acoustic performance in the space. This optimization can be done with algorithms such as genetic algorithm or swarm intelligence. A variety of material options can be included in this type of optimization to achieve a better architectural solution.

Studies on the methodology of creating complex forms can reveal forms in different morphologies. These different morphological forms may have different features in relation to various parameters such as acoustic, structure. Therefore, studies on testing of complex forms at various complexities may lead to the discovery of more optimized morphologies.

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