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Article

Development of Floor Structures with Crumb Rubber Efficient for Floor Impact Noises

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Abstract: Korea has a high density of population, considering the size of the territory. So, the importance of convenient and comfortable apartment buildings and high-rise residential-commercial complex buildings has been rising. In addition, because of the improvement of the standard of living along with continuous national economic growth, the interest in wellbeing and the expectation of quiet life for comfortable and pleasant residential environment have also been increasing. However, Korea has the lifestyle of sitting on the floor, so floor impact sound has been occurring more and more frequently. Because of that, unneighborly disputes have been a serious social problem. And lately damage and disputes from noise between floors have been much more increasing. The present work, therefore, used waste tire chips as a resilient material for reduction of floor impact sound in order to recycle waste tires effectively. Also, a compounded resilient material, which combines EPS (Expanded Polystyrene), a flat resilient material of the upper part with waste tire chips of the lower part, was developed. After constructing waste tire chips at a standardized test building, experiments of both lightweight and heavy-weight floor impact sound were performed. The tests proved that it was possible to control effectively both the lightweight and heavy-weight impact sound, when using waste tire chips as a resilient material for reduction of floor impact noise.

Keywords: Floor impact sound; Crumb rubber; Floor structures; Lightweight and heavy-weight impact noises

1. Introduction

As for the improvement of living level along with the continuous growth of national economy, the interest in the well-being of residents is increasing. Accordingly, the interest of residents is increasing in a quiet living for the comfortable and pleasant residential environment. Especially, due to the high weight on the apartment and the living habit of a sitting type, the occurring frequency of a floor impact noise is so high that its damage and conflict occur often in reality. By this reason, in domestic, studies and developments are continuously in progress to block the noise between floors. As a result of it, the current major block type for the floor impact noise used in domestic, only increases the thickness of structural slabs or uses the resilient materials of light quality such as EPS and EVA. [1] However, this kind of structure has such a problem that it not only increases the floor thickness but also the total construction cost.[2]

As the measuring method of dynamic modulus of elasticity of resilient material for the floor impact noise was established, the interest in the performance of resilient material has been heightened, and its performance has been recognized as the important element for the reduction of the floor impact noise. According to the study result by J.W. LEE, in case of the light impact noise, it shows a tendency that, as the dynamic modulus of elasticity increased, the reduction amount was reduced in large scale; and that in a constant level, it was reduced by the ratio of exponential function without

any change but was maintained. It was shown that within the range of dynamic modulus of elasticity of 20~80MN/m³, there was a change of about 5~6dB.[3] In a study by K.W. Kim, the relationship between the dynamic modulus of elasticity and the reduction amount of heavy impact noise of resilient material for the floor impact noise was identified, and the coefficient of determination was shown to be higher in most of frequencies. Therefore, it was shown that, if the resilient material with the dynamic modulus of elasticity of 8MN/m³ and below is used to reduce the heavy impact noise, it might prevent the resonance which occurs at 63Hz. In addition, the dynamic modulus of elasticity of resilient material decreased when materials with different quality were layered, and the reduction amount of light impact noise in-creased.[4] Also, according to the study of J.K RYU, in case of the resilient material in EPS series, it was shown that the products which contain embossing at the bottom had the improving effect of performance for the heavy impact noise, which was not a simple in-crease of thickness. In case of the resilient material in EVA series, it was found out that by the composition of complex materials of EP net and noise absorbing material, the reduction performance for the heavy impact noise was improved.[5] The study by J.H. Kim investigated the effect of resilient materials on heavy-impact sound in wall-structured apartment buildings. According to the research results, it was found that, generally, as the dynamic modulus of elasticity increases, the sound pressure level also increases at frequencies above 80 Hz. The responses at 50 Hz, 60 Hz, and 80 Hz showed amplification due to the resonance phenomenon of the resilient materials, and the frequency at which this amplification occurs varied depending on the type of resilient material.[6] Lee undertook floor impact noise tests using 19 different resilient materials, including EVA, PET, PP, and PS sheets. The results showed that a maximum reduction of 5dB in heavy-weight floor impact noise could be achieved compared to a bare concrete slab.[7] Similarly, Kim measured the dynamic elastic modulus of nine specimens comprising EVA, EPS, PE, crumb rubber, and glass fiber materials. He found that the dynamic elastic modulus decreases with increasing thickness of the composite materials, regardless of the type of resilient material used.[8] Another similar experiment used 20mm of EVA resilient material with a concrete slab of 180mm thickness, resulting in a 2dB reduction in heavy-weight floor impact noise.[9] Considering from the above results, as for the composition of resilient material, it is predicted that the complex composition of materials with different quality will lower the dynamic modulus of elasticity and have the improvement of reduced performance for the light and heavy impact noises.

Therefore, much research are discussed with the composition of various elastic materials. According to the thickness and composition of the buffer material, the thicker the buffer layer, the lower the dynamic modulus, thereby reducing the weight impact sound. [10] As a result of investigating the difference in the reduction performance of the floor impact sound through shape transformation for the EVA single material, it was confirmed that there is an effective shape difference according to the frequency characteristics of the impact sound.[11] Furthermore, studies have shown that the floor impact sound reduction performance can be improved by adjusting the composition ratio of the buffer material, even when using the same material.[12, 13]

Especially, the annual global production of waste tires is estimated to be around 1 billion units (approximately 17 million tons) [14], and this figure is expected to continue to increase due to global population growth and the rising number of automobiles in emerging countries. Accordingly, recycling waste tires by shredding them into tire chips offers advantages such as reducing environmental burden and lowering overall construction costs due to the low material cost. Due to their cost-effectiveness and environmental friendliness, waste tire chips are used as various additional materials. Research results have been published that have proven usability by mixing waste tire chips with wood. [15] Based on the evaluation method proposed by the Japanese Architectural Association, research has shown that waste tire chips can effectively block lightweight impact sound. [16] Crumb rubber is also a prospective material with a high block performance in the floor impact noise due to a high elasticity and a gap which occurs between particles. In addition, utilizing the crumb rubber with a crushed type is convenient to use those as a layered structure, and will be used for various fields. In a study by Navid Chalangaran, waste tire chips were added to concrete to create samples, and the sound insulation performance was measured using an impedance

tube to recycle waste tires. It is concluded that substituting sand aggregates with rubber crumbs specimens containing 15% fine-grained crumbs or 15% coarse-grained crumbs could improve the STL by up to 190% and 228%, respectively, while the implementation of 5% and 10% rubber crumb material has desirable effects on reducing low-frequency noises.[17] In the study by Anu Bala, thermal resistivity and sound absorption performance were measured for rubberized concrete (RC), in which waste tire chips were incorporated into concrete. Increasing rubber content in-creases the porosity of the concrete mix, thereby increasing thermal resistivity and sound absorption.[18] However, when crumb rubber is mixed with concrete, the compressive strength is lowered, so these structural limitations must be solved.[19]

Therefore, in this study, by applying the crumb rubber as a resilient material for the floor impact noise, such resilient material shall be developed that can control the impact noise in the current floor structure system. Also, based on the dynamic characteristic according to the change in the composition of resilient material for the floor impact noise, the study for a method shall be performed, which can satisfy the block performance for the floor impact noise.

2. Experiment

2.1. Outline of Experiment

In order to check the reduction performance for the floor impact noise of resilient material, an experiment was proceeded in the standard test room for the floor impact noise in which the construction of floor structure was equivalent to the apartment located in K.C.L. (Korea Conformity Laboratories)

The standard test room for the floor impact noise consists of a total of sixteen sound receiving rooms on the first floor and sound source rooms on the second floor with the same size of spaces. The inner size of each room has a rectangular space of 4.5×5.1(m), and the thickness of every floor slave is 180mm. The sound receiving room is required to be installed with a plaster ceiling with 100mm air space thickness. The following Table 1 shows the summary of building dimensions of the standard test room for the floor impact noise.

Table 1. Architectural dimension of standard test room for floor impact noise.

Classification	Architectural dimension of standard test room
Length (L)	5.1 m
Width (W)	4.5 m
Height (H)	2.5 m
Volume (V)	58.6 m ³
Floor area (F)	22.9 m ²
Thickness of slab	180 mm

2.2. Method of Experiment

The measurement for the floor impact noise was measured and evaluated, based on KS F 2810-1,2 by the standard onsite measuring method. Through the following Figure 1, the outline diagram of experiment has been expressed. Five sites were selected for the installation position of impact source in the sound source room including the center point. It was installed with 0.75 m separated from the surrounding walls of the room, and it is as in Figure 2. Five sites were selected for the installation position of microphone including the center point of receiving room equivalent to the installation position of impact source in the sound source room. It was installed at the 1.2 m height from the floor at the site separated by 0.75 m from the walls of the surrounding room.

2.3. Objectives of Experiment

Based on the results of previous studies, design criteria for the resilient material was completed by using crumb rubber and EPS complexify. Especially, at the time of reviewing the design criteria

for the resilient material, the reduction performance of the floor impact noise was compared by changing the particle size of crumb rubber within the range of thickness of resilient layer unchanged.

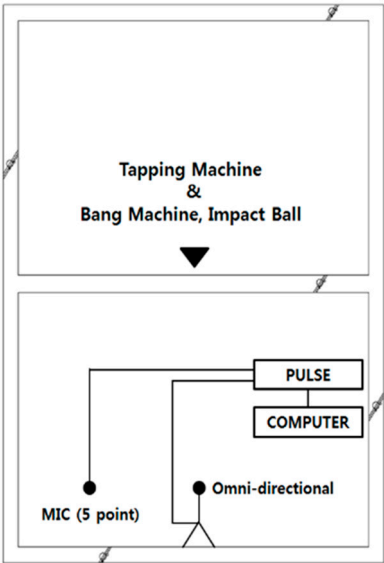


Figure 1. Experiment set-up apparatus.

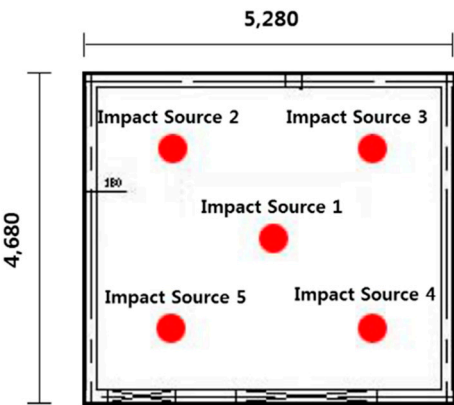


Figure 2. Points of floor impact source.

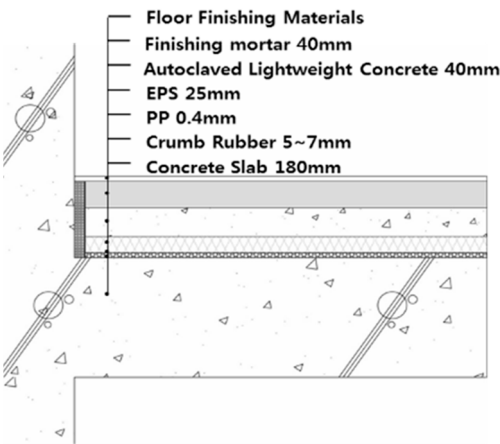


Figure 3. Section of floor type 1 (crumb rubber 5~7 mm, EPS 25 mm).

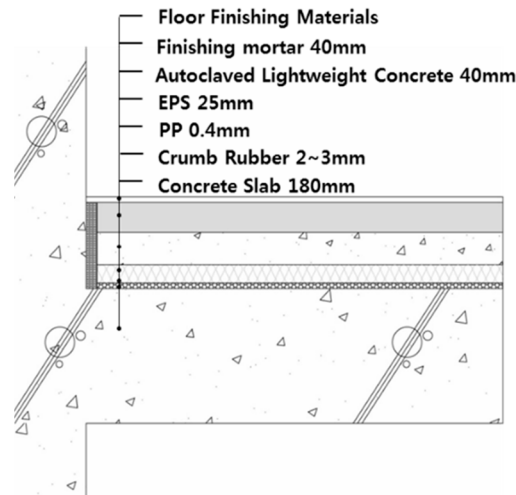


Figure 4. Section of floor type 2(crumb rubber 2~3 mm, EPS 28 mm).

Also, PP sheet was used between layers of EPS and crumb rubber, and the reason was that the crumb rubber may cause deformation by penetrating the light quality EPS which is layered at the top part. Also, it may lower the reduction performance for the floor impact noise as the area increases in which the floor slave contacts with EPS. Therefore, to solve this kind of problem, a structure was completed which had inserted PP sheet between crumb rubber and EPS layer.

The experiment was performed for objectives of floor Type 1 with a particle size of crumb rubber 5~7 mm, PP sheet 0.4 mm, EPS 25 mm and floor Type 2 with a particle size of crumb rubber 2~3 mm, PP sheet 0.4 mm, EPS 28 mm. The following Figures 3 and 4 show the cross sections of floor Type 1 and 2 of floating floor structure according to the change of particle size. Especially, as the resilient material for the floor impact noise had a weak re-reduction performance, to check the reduction performance for the heavy impact noise level from the measured result of floor impact noise, the heavy impact noise level was measured for the objective of 180 mm concrete slave, excluding the construction of floating floor structure.

3. Results

Table 2 shows the floor impact noise standards of Korea for lightweight and heavy-weight impact sound with four different grades that have been implemented since 2006. These standards have been implemented to ensure acceptable levels of noise within residential buildings, improving the quality of living by mitigating floor impact noise.

Table 2. The floor impact noise standards of Korea.

Classification	Light-weight impact sound	Heavy-weight impact sound
	($L'_{nT,w}$)	($L'_{I, Fmax}$)
1 st grade	$L'_{nT,w} \leq 37$	$L'_{I, Fmax} \leq 37$
2 nd grade	$37 < L'_{nT,w} \leq 41$	$37 < L'_{I, Fmax} \leq 41$
3 rd grade	$41 < L'_{nT,w} \leq 45$	$41 < L'_{I, Fmax} \leq 45$
4 th grade	$45 < L'_{nT,w} \leq 49$	$45 < L'_{I, Fmax} \leq 49$

3.1. Floor Impact Noise Level by Standard Light-weight Impact Source(Tapping Machine)

The value of floor impact noise level by the standard light impact source was computed for the 1/3 octave band with the level which had modified the background noise. A comparison graph for the light impact noise level according to the frequency per TYPE of level computed by this is as in Figure 5. As shown in the Figure 5, through the values of the light impact noise level by the standard light impact source, in case of floor Type 2, the reduction performance for the light impact noise was

improved. By that reason, according to the study result by K.W.Kim, it can be known that, as the thickness of resilient material became thicker, the reduction performance of the light impact noise increased.[4] Accordingly, it is judged that even though the thickness of resilient materials complex composition' was the same as 30 mm in case of floor Type 2, the effective thickness of EPS for the reduction performance of the light impact noise appeared to be 3 mm thicker than that of floor Type 1. On the other hand, it was shown from the study result that, if the dynamic modulus of elasticity of resilient material increased, the reduction performance of the light impact noise also decreased. However, it was shown that, although the dynamic modulus of elasticity in floor Type 2 was higher than that of floor Type 1, the reduction performance of the light impact noise was excellent.

When the light impact noise levels of floor Type 1 and 2 per frequency were compared, it can be known that in both floor Type 1 and 2, as for the result which had generally appeared from the resilient material for the floor impact noise utilizing EPS, the light impact noise level became lower as it is moved to the middle & high frequency bands.

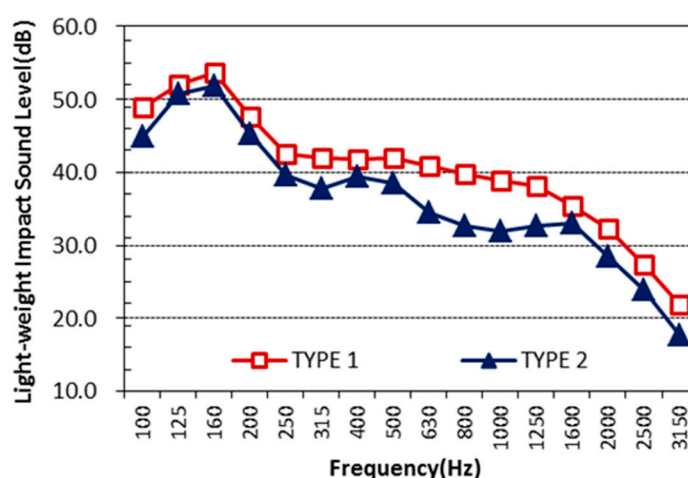


Figure 5. Comparison of light-weight impact noise level of floor type 1 and floor type 2.

3.2. Floor Impact Noise Level by Standard Heavy-weight Impact Sources (Bang Machine, Impact Ball)

The value of floor impact noise level by the standard heavy impact source was computed for the 1/3 octave band with the level which had modified the background noise. Especially, the reduction characteristic of heavy impact noise level by the floor impact noise resilient material utilizing crumb rubbers was compared and analyzed with the heavy impact noise level measured at slaves only.

3.2.1. Bang Machine

The value of floor impact noise level by Bang Machine was computed for the 1/3 octave band with the level which had modified the background noise. The measured result of the heavy impact noise level computed by this is as in Figure 6. It was shown that in the Figure 6, through the value of heavy impact noise level by Bang Machine among the standard heavy impact sources, the resilient material of floor Type 2 showed the higher reduction performance of heavy impact noise than that of floor Type 1. In addition, the reduction performance of heavy impact noise showed outstanding in the low frequency band, which is the major cause for the noise between floors by the heavy impact noise. In the previous studies of this thesis, it was shown that the lower the dynamic modulus of elasticity was, the higher the reduction performance was. However, from the result of actual construction of resilient material in the standard experiment room for the floor impact noise, it was shown that the reduction performance of floor Type 2 with the higher dynamic modulus of elasticity was more excellent. It is believed that the difference of dynamic modulus of elasticity per TYPE was minimal, and also that when the composition of resilient layers of floor Type 1 and floor Type 2 was compared, the particle size of crumb rubbers might have affected the reduction performance of heavy impact noise. When the block performance of heavy impact noise per frequency was compared, it

can be verified that at 50 Hz, the heavy impact noise level increased more when resilient materials were installed than when only the slaves were installed. In case of concrete slave, it seemed that the inherent vibration frequency of resilient material by the heavy impact source installed for 63 Hz band (40 Hz~80 Hz) was located at 50 Hz to generate the resonance and rather to increase the heavy impact noise level.

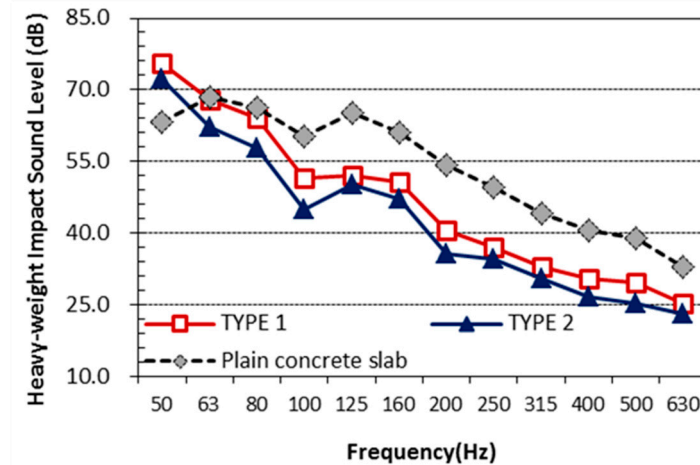


Figure 6. Comparison of heavy-weight impact noise level of floor Type 1 & 2 with plain concrete slab (Bang-machine).

3.2.2. Impact Ball

The value of floor impact noise level by Impact Ball was computed for the 1/3 octave band with the level which had modified the background noise. The measured result of the heavy impact noise level computed per floor Type by this was compared by the frequency and shown in Figure 7. It was shown in the Figure 7 that, through the value of heavy impact noise level by impact Ball among the standard heavy impact sources, the reduction performance of the heavy impact noise of floor Type 2 was higher than that of floor Type 1, same as in the Bang Machine. Especially, the difference of the reduction amount of heavy impact noise in the 80 Hz band excluding 50 Hz and lower showed to be higher than that in the frequency band above 125 Hz. In the frequency band of 125 Hz and higher, the re-reduction amount of floor Type 1 and floor Type 2 showed almost similar.

When the block performance of heavy impact noise per frequency was compared, it can be verified that the heavy impact noise level rather increased when the resilient material was installed at 50 Hz than when slaves were installed only, which was equivalent to the heavy impact noise level measured by the Bang Machine as the heavy impact source.

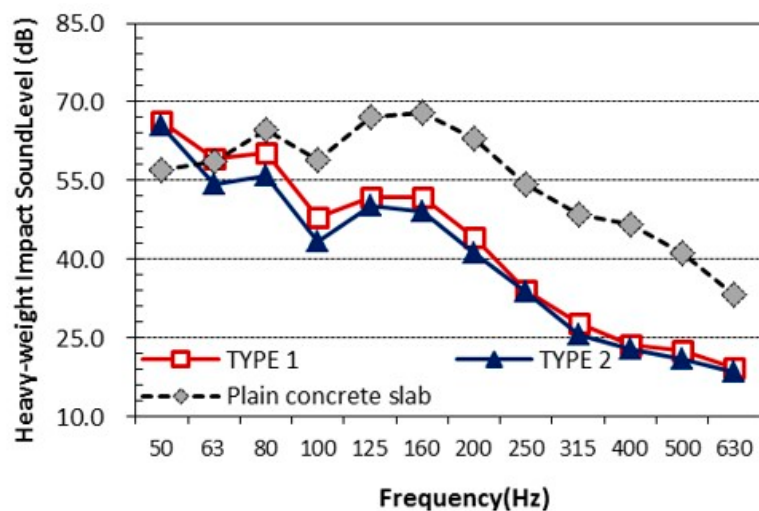


Figure 7. Comparison of heavy-weight impact noise level of floor Type 1, 2 and plain concrete slab (Impact ball).

3.3. Performance Grade of Floor Impact Noise of Resilient Material Utilizing Crumb Rubber

The block performance of the floor impact noise of resilient material utilizing crumb rubber was evaluated through the grade standard of the block performance of floor impact noise according to the detailed measuring standard in the management standard of floor impact noise. Table 3 shows the impact noise level by evaluating the floor impact noise according to KS F 2863, which was measured by exciting the standard light impact source and heavy impact source.

Accordingly, the grade standard has been marked for the block performance of floor impact noise. It was shown that for floor Type 1, the block performance of the floor impact noise of resilient material utilizing crumb rubber corresponded to the first grade in the light impact noise, and among heavy impact noises, the third grade in case of exciting the Bang Machine, the second grade in case of exciting the Impact Ball. For floor Type 2, it was shown that the block performance was the first grade in the light impact noise, and in case of exciting the Bang Machine and the Impact Ball, both showed the second grade.

Table 3. Floor impact sound insulation performance grade of floors using resilient material and crumb rubber.

Impact source	Type 1		Type 2	
	Impact sound level (dB)	Class	Impact sound level (dB)	Class
Tapping machine	39	1	35	1
Bang machine	46	3	42	2
Impact ball	40	2	38	2

4. Conclusions

In this study, based on the resilient material designed for the floor impact noise utilizing crumb rubber, the floor structure was constructed in the standard test room. The floor impact noises were measured, and the reduction performance was analyzed. The result of this study can be summarized as follows.

1) When the standard impact source was excited, the reduction performance of the resilient material of floor Type 2 showed excellence for both the light impact noise and the heavy impact noise.

2) It was predicted that the block performance of the floor impact noise of floor Type 2, which has a lower dynamic modulus of elasticity, would be poorer than that of floor Type 1, but it showed that the performance of floor Type 2 was excellent at the time of onsite measurement.

3) In both floor Type 1 and 2, a resonance was generated at 50 Hz so that the heavy impact noise was not reduced but rather increased.

4) For floor Type 1, the block performance in the light impact noise satisfied the first-grade standard, and among the heavy impact noises, the third-grade standard when exciting the Bang Machine, the second-grade standard when exciting the Impact Ball. For floor Type 2, the block performance satisfied the first grade in the light impact noise, and the block performance in the heavy impact noise satisfied the second-grade standard when exciting both the Bang Machine and the Impact Ball.

5) Regardless of the different characteristics of impact sources which the Bang Machine and the Impact Ball have as the standard heavy impact source, floor Type 2 showed the reduction performance of floor impact noise which was similar to those two impact sources.

Through the present study, utilizing the crumb rubber as a resilient material for the floor impact noise, it has been judged that the reduction performance of floor impact noise was excellent. In addition, supplementing the weak resilient material to the reduction performance of heavy impact

noise, an effective structure has been developed for controlling the heavy impact noise. It is judged that in the future, it will be necessary to verify the reduction performance of floor impact noise by constructing at the actual field of apartment.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualization, C.H.Haan.; methodology, C.H.Haan.; software, C.H.Haan.; validation, J.H.Park and C.H.Haan.; formal analysis, J.H.Park.; investigation, J.H.Park.; resources, X.X.; data curation, J.H.Park.; writing—original draft preparation, J.H.Park.; writing—review and editing, C.H.Haan.; visualization, J.H.Park.; supervision, C.H.Haan.; project administration, C.H.Haan.; funding acquisition, C.H.Haan. All authors have read and agreed to the published version of the manuscript.” Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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