

Article

Evaluation of Construction Cost, Time, and Sustainable Attributes of Drywalls Supported by Resilient Channels

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Received: 9 September 2020; Accepted: 27 September 2020; Published: 1 October 2020



Abstract: In this study, a gypsum board wall was developed using resilient channels to improve sound insulation performance, constructability, and economic efficiency; the effect of the application of the developed wall on skyscrapers and long-term housing, one of the main forms of modern buildings, was also comprehensively evaluated. Resilient channels were inserted and fixed to ensure the constructability was suitable for high-rise buildings. In addition, the sound insulation performance, durability of the wall, CO₂ emissions, and life-cycle cost (LCC), which are key elements for economic efficiency, constructability, and sustainability, were analyzed. The developed lightweight gypsum board drywall with resilient channels was compared with a concrete wall as well as a double stud gypsum board wall, which has been most widely used among existing drywalls. The sound insulation performance and durability were evaluated in a laboratory, and the other items were evaluated after constructing the walls in a hotel building with an area of 2956 m². The evaluation results show that the developed wall exhibited a 3 dB higher sound insulation performance than the concrete wall, even though it was thinner by 50 mm, and the wall secured the grade of “severe duty” (SD) based on the BS 5234-2 standard in durability evaluation, indicating that it can sufficiently replace concrete walls. Moreover, when the developed wall was installed in an actual building and compared with a concrete wall, a 14.7% reduction in construction cost, 59% reduction in CO₂ emissions, and 30.4% reduction in the LCC of the drywall, considering even the remodeling and dismantling stages of the building, were observed. Therefore, it was proven that the newly developed resilient channel drywall with improved constructability has significant value in terms of sound insulation performance, economic efficiency, safety, and eco-friendliness.

Keywords: sound insulation; gypsum board; life-cycle cost; carbon dioxide

1. Introduction

In recent years, demands for new types of drywalls that utilize space efficiently and improve sound insulation performance have been increasing in skyscrapers, mixed-use residential buildings, apartments, schools, medical facilities, and other accommodations [1]. In particular, hotels, offices, or medical facilities where sound insulation performance and personal privacy are important, noise insulation performance leads to consumer satisfaction [2], and securing a larger area by reducing the wall thickness increases economic efficiency by increasing the number of hotel rooms and hospital beds. Moreover, in skyscrapers, walls with excellent sound insulation performance that are lightweight and not very thick have been identified as essential in increasing building height and providing a comfortable living environment. In addition, there is growing interest in drywalls that are favorable in terms of constructability and variability, as consumer demands for floor plans have diversified; and demands for interior remodeling of apartments have increased lately. Although some

studies have been conducted on changes in the sound insulation performance when concrete walls are replaced with gypsum board drywalls, the effect of such replacements on other components affecting building performance has not been investigated sufficiently [3].

In cases of mass construction, such as skyscrapers and apartments, detailed research on items such as construction cost, construction time, durability, maintenance cost, and CO₂ emissions is required owing to changes in the construction method; usually, only the sound insulation performance needs to be compared. In a previous study related to gypsum board drywalls, technologies for increasing the wall thickness or wall weight were applied to secure a sound insulation performance similar to that of a concrete wall [4]. This offsets the benefits of the lightweight wall and replaces them with the characteristics of concrete. In the case of drywalls designed to have sound insulation performance, the mass of materials is similar to concrete; a double stud structure, in which studs and runners are arranged in two rows, is usually applied [5–7]. These types of walls increase the thickness by placing an air layer in the middle or adding heat-insulating materials, thus, requiring a long construction time and having a high construction cost. Therefore, various types of studs appeared to improve the sound insulation performance of drywalls because studs have the greatest influence on performance; this has been proven by a number of studies [8–10]. As the existing C-studs (used as the vertical support in wall framing) have little damping function in the vibration transmission path, studs with elasticity have been developed and recently used to improve the sound insulation performance. The resilient channel method has the same purpose. Resilient channels are added to C-studs in the vertical direction to separate the gypsum board and C-studs. Therefore, the sound insulation performance is improved, but the time and cost to install the resilient channels are added. Given these limitations, there are not many cases in which resilient channels have actually been applied to mass high-rise building construction sites.

As such, this study proposes a new construction method that can improve the limitations of existing resilient channel drywalls used in mass construction. The research questions of this study are as follows:

- (1) Is the proposed resilient channel method beneficial in terms of sound insulation performance?
- (2) Is the proposed resilient channel method beneficial in terms of durability?
- (3) Is the proposed resilient channel method beneficial in terms of economic efficiency?

To answer the above questions, a method enabling mass construction and maintaining the constructability of the resilient channel drywall was developed and applied to actual construction sites. In addition, an attempt was made to comprehensively analyze the structural stability, constructability, economic efficiency, life-cycle cost (LCC), and CO₂ emission reduction in addition to improving the sound insulation performance. The sound insulation performance was measured in accordance with ISO 10140-2:2010 [11], and single-number quantities were calculated using ISO 717-1 [12]. Vibration measurements were also performed to evaluate the reduction in the vibration transmitted to the surface of the drywall. The durability of the drywall was evaluated in accordance with BS 5234-2 [13], and its lateral load resistance and impact resistance were analyzed.

As for previous studies related to double walls that used lightweight steel, most of them were conducted to analyze the sound insulation performance, and studies on sound insulation performance according to the lightweight steel and sound-absorbing materials, which are connecting members between the panels on both sides, were conducted based on the laboratory measurement data [14,15]. Most of the studies evaluating the sound insulation performance of materials that constitute double walls (façade material, studs, runners, and sound-absorbing material) have been conducted based on field tests, and the main research targets have included the mass and stiffness of panels as well as panel separation, cavity fillings, and studs (type, spacing, and materials) [16–18]. Quirt and Warnock [17] published a report that analyzed these contents based on the actual measurement results. They revealed that studs have a substantial influence on the sound insulation performance in double walls and that the number, type, and installation spacing of studs are important factors determining the sound insulation

performance of double walls. They also reported that lightweight steel studs exhibited better sound insulation performance than wood studs in a sound insulation experiment. Meanwhile, previous studies related to methods that use resilient channels were conducted with a focus on the geometry or thickness of resilient channels and the difference in sound insulation performance depending on the panel types attached to resilient channels [19–21]. Bradley and Birta mentioned that a resilient structure is a mass–air–mass system in which resilient channels serve as springs and the attached panels serve as the mass and conducted modeling research on the sound insulation performance of such resilient structures [21]. They calculated the dynamic stiffness of each structure by evaluating the sound insulation performance for various types of resilient channels. Brunskog and Hammer also proposed a method for measuring the frequency dependency of the transfer stiffness and input stiffness of the resilient channel of a resilient structure [20]. Paul et al. [19] compared the sound insulation performance between walls with and without resilient channels and reported that the application of resilient channels improved the sound insulation performance by up to 10 dB in a specific frequency range and by approximately R_w 5 dB for a single evaluation index. Most previous studies have been focused on predicting the sound insulation performance of double-wall structures or evaluating the sound insulation performance based on measurement data. However, to apply drywalls to mass construction sites such as skyscrapers, it is necessary to examine items such as the constructability, economic efficiency, structural stability, and ease of maintenance in addition to the sound insulation performance. In particular, by increasing the service life and height of modern buildings, the use of lightweight gypsum board walls is expected to further increase compared to concrete walls for reducing the weight of buildings.

2. Materials and Methods

2.1. Proposed Installment of Resilient Channel Walls and Sound Insulation Performance Evaluation

With respect to the installation of the newly developed wall, the existing construction method fixes resilient channels to C-studs at regular intervals using screws, as shown in Figure 1 [22]. Therefore, it is necessary to mark points at which screws are to be fastened on the studs in advance, and a worker should hold the resilient channel on both sides when fixing the screws. This increases the construction cost and acts as a large entry barrier, considering skyscrapers are predominantly mass-constructed.



Figure 1. Resilient channel installation method (workers are fixing resilient channels to C-studs using screws).

To address this problem, a clip (left panel in Figure 2) that can be installed on the C-studs through punching at regular intervals to insert and fix the resilient channels was devised in this study. This allows one worker to easily install resilient channels. As the clips are formed at regular intervals and it is no longer necessary to mark points for resilient channels in advance, the construction time can be shortened.

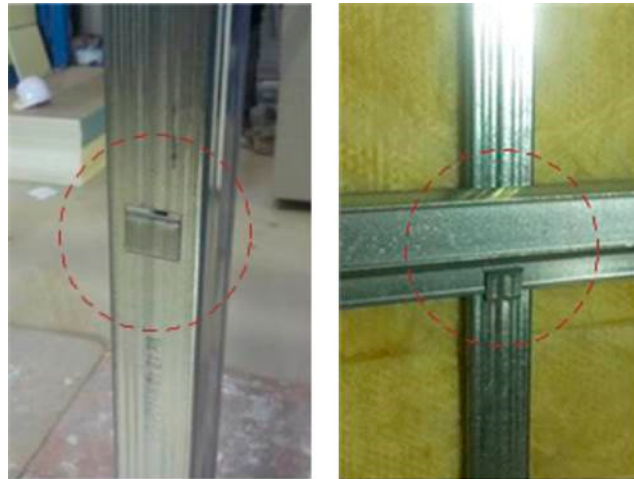


Figure 2. System developed to install resilient channels (a single worker can fix resilient channels to C-studs using clips, which are highlighted by red circles).

2.2. Performance Evaluation of the Proposed System

2.2.1. Evaluation of Sound Transmission Loss

Resilient channel drywalls have been widely used since their development in the United States and Europe in the 1960s. In particular, they have been used in ceilings and floors in addition to walls to reduce noise and vibration [23]. They improve the sound insulation performance of walls by separating the gypsum board and studs, thereby reducing the transmission of vibrations. The transmission of vibrations in conventional drywalls can be defined by Equation (1):

$$T = \sqrt{\frac{1 + 4D^2\left(\frac{f}{f_0}\right)^2}{\left[1 - \left(\frac{f}{f_0}\right)^2\right]^2 + 4D^2\left(\frac{f}{f_0}\right)^2}} \quad (1)$$

where T is the shear rate, D is the damping ratio, f is the frequency, and f_0 is the resonance frequency. Here, a wall composed of two panels with air space has the mass-air-mass resonance determined by the stiffness of the air and the mass of the finishing plates, as shown in Equation (2):

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{s}{m}} \quad (2)$$

where s is the stiffness per unit area, and m is the mass of the plates. In addition, the stiffness of the air layer with a thickness of d can be obtained using Equation (3):

$$S = \frac{\rho_0 c^2}{d} \quad (3)$$

where ρ_0 is the air density, and c is the speed of sound. When resilient channels are installed, however, their stiffness (s_2) must be added to the stiffness s_1 of the air layer (s_1). Thus, Bradley and Birta proposed Equation (4):

$$S = S_1 + S_2 = \rho_0 c^2 \left(\frac{1}{d_1} + \frac{1}{d_2} \right) \quad (4)$$

Substituting Equation (4) into Equation (2) yields:

$$f_{0,R} = \frac{1}{2\pi} \sqrt{\rho_0 c^2 \left(\frac{d_1 + d_2}{d_1 d_2} \right) \left(\frac{m_1 + m_2}{m_1 m_2} \right)} \quad (5)$$

Equation (5) shows that the installation of resilient channels shifts the resonance frequency of the drywall to a lower frequency. To prove this, the airborne sound insulation performance of an actual wall was evaluated. In addition, accelerometers were attached to the surface of the gypsum board, and its vibration was measured to observe the movement of the resonance frequency to a lower frequency by the resilient channels. For comparison with existing technology in terms of sound insulation performance, a double stud wall, which is a type of widely used drywall, and a resilient channel wall were constructed and compared, as shown in Figure 3. The reverberation chamber sound insulation performance was evaluated in the Kumkang Coryo Company (KCC) acoustics laboratory, in accordance with ISO 10140-2;2010 [11] and ISO 717-1 [12].

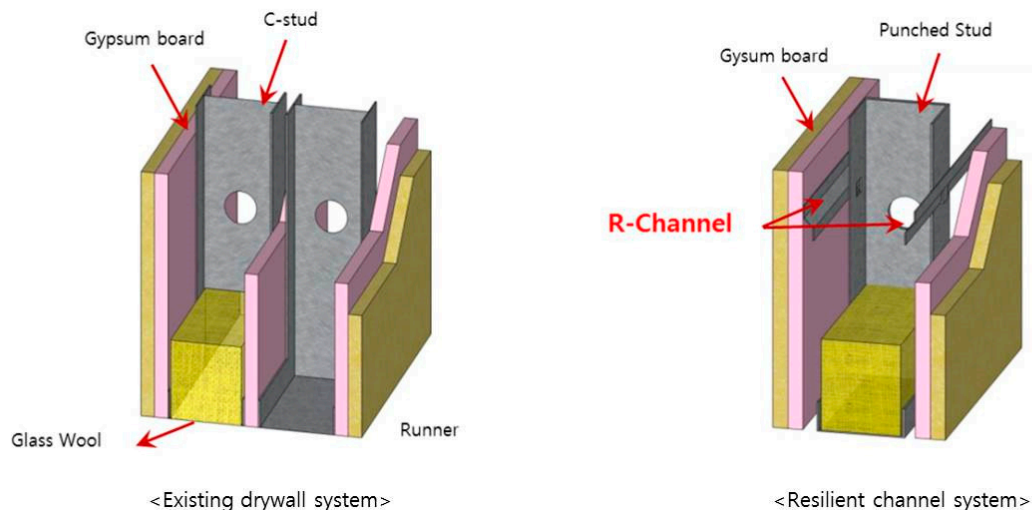


Figure 3. Test wall diagrams.

2.2.2. Evaluation of Durability

As gypsum board drywalls are applied to boundary walls between households—or walls inside a household in which occupants are present—in addition to various wall categories, there is growing interest in their structural stability. This is because occupants have a perception that gypsum boards are weaker in strength and, thus, more easily broken than conventional concrete walls. Therefore, the structural stability of a wall constructed with resilient channels was evaluated based on the standards of BS 5234-2 [13]. A specimen was fabricated in a frame of 3000×3000 mm, and its impact resistance and lateral load resistance were evaluated, as shown in Figure 4. A sandbag was used as a soft impact source and a metal ball as a hard impact source.

2.2.3. Evaluation of Constructability, Economic Efficiency, CO₂ Emissions, and LCC

Resilient channel walls can secure high sound insulation performance despite their thin wall thickness, as described above. They have higher economic efficiency than concrete walls and double stud gypsum board walls and are expected to be beneficial in terms of their environmental load and maintenance cost because they require few input materials. Therefore, resilient channel walls were constructed in an actual building, and quantitative analysis was conducted on their economic efficiency, constructability, LCC, and CO₂ emissions. The building selected was the Seoul City Hotel (total area: 2956 m²) located in Seoul, South Korea, and resilient channel gypsum board walls were applied to all walls inside the building. The economic efficiency for the material was evaluated as well as construction costs per unit wall area, and the constructability was calculated based on the actual input of manpower for construction. As resilient channel drywalls were applied to this site, the construction cost of concrete walls or double-stud walls was analyzed and compared based on the average construction cost of other buildings where similar walls were applied.

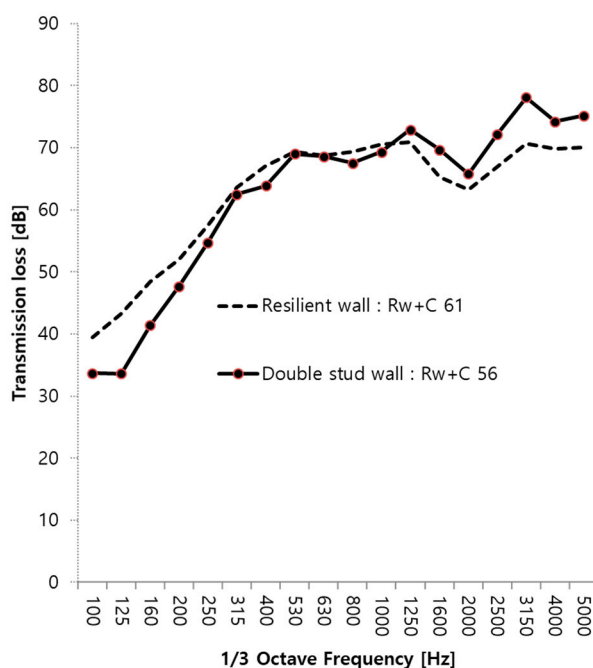


Figure 4. Result of the sound transmission loss test.

3. Results

3.1. Result of the Sound Transmission Test

Figure 4 shows the results of measuring the sound insulation performance of the resilient channel drywall and conventional double stud drywall. The $Rw+C$ value, used as a measurement index, is the index spectrum adjustment term (C) to correct the single-number rating (Rw) and receiver frequency characteristics. The resilient wall (wall thickness 150 mm) was found to have a sound insulation performance approximately 5 dB higher than the conventional double stud wall (wall thickness 200 mm), even though it was 50 mm thinner. The conventional double stud method could not exhibit an improved sound insulation performance as expected due to the resonance inside the wall, despite the placement of two rows of studs. The resilient method, however, exhibited a 10–15 dB higher sound insulation performance than the double stud method at 100 and 125 Hz because the wall stiffness value decreased due to the elasticity of the resilient channels despite a thinner wall thickness. However, in the high-frequency range of 1000 Hz or higher, the conventional double stud method, in which one more gypsum board was installed in the air space, showed a 2–5 dB higher sound insulation performance. This is because the sound insulation performance in that range is increased by the mass per unit area of the structure.

The excellent sound insulation performance of the resilient channel wall in the low-frequency range was also observed in the vibration transmission measurement results. As shown in Figure 5, vibration sensors were installed in the source and receiving rooms. After generating sound through the speaker in the source room, the vibration transmitted to both walls was measured at the same time. It was found that the conventional drywall with air space exhibited a sound insulation performance reduction effect at approximately 125 Hz due to the low-frequency resonance, even though there were some differences depending on the thickness of the gypsum board. However, for the resilient channel wall, the low-frequency resonance phenomenon moved to the 80–110 Hz band, as shown in Figures 5 and 6. It appears that the resonance phenomenon occurred in a frequency range lower than 110 Hz due to the resilient channels, having lower stiffness values than that of air. Considering that the sound insulation performance evaluation target of ISO is the 100–3150 Hz range, the sound insulation

performance was effectively improved by moving the low-frequency resonance phenomenon out of the evaluation target range.

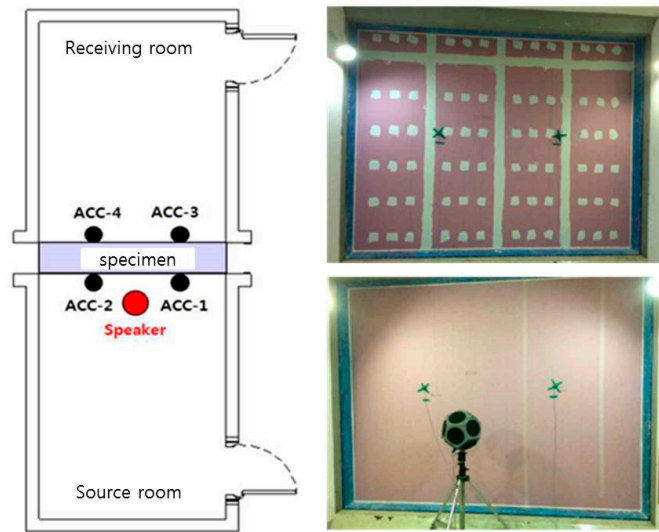


Figure 5. Vibration measurement test.

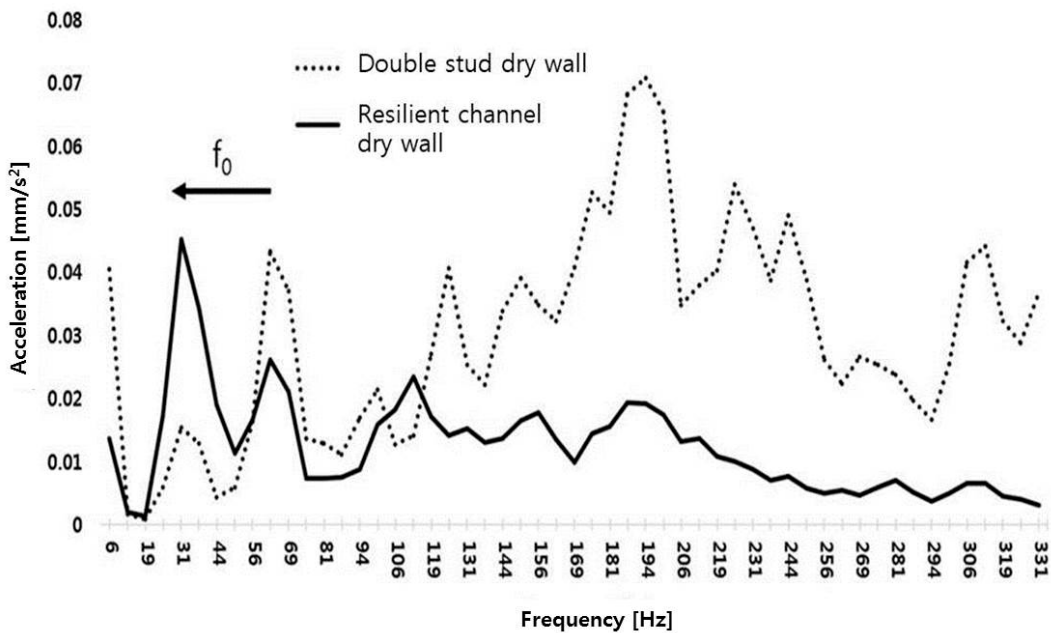


Figure 6. Vibration measurement results.

3.2. Evaluation of Durability

In BS 5234 Part 2 [13], the evaluation criteria for the lateral load resistance and impact resistance are established, as shown in Table 1, and walls with the highest grade according to the measurement results are defined as SD (“severe duty”) grade. The walls of this grade can be applied to all buildings.

Based on the above evaluation criteria, the maximum and residual deformations were measured and evaluated in the lateral load test by applying 50 kg to the resilient channel structure, and the structure secured the SD grade because the residual deformation was less than 1 mm. In the impact resistance test, the structure was hit by a soft body and then by a hard body to evaluate the damage to the wall. After the structure was hit by a 30 kg sandbag used as a soft impact source, the maximum and residual deformations were measured. The structure secured the SD grade because the residual

deformation after an impact of 100 N·m was less than 2 mm (0.8 mm). A 3 kg metal ball was used as a hard impact source, and an impact of 30 N·m was applied to the structure using the ball. The structure secured the SD grade because there was no penetration after impact. Although BS 5234 Part 2 assigns the SD grade if there is no penetration after an impact of 10 N·m, the impact was increased to 30 N·m during the test because the hard body test was judged to have an organic relationship with the local damage that frequently occurs in real life. The test results showed that no penetration occurred at 30 N·m, which is an impact that exceeds the threshold value for the SD grade. Therefore, the wall constructed using the developed method was evaluated to have sufficient durability to be used in all buildings.

Table 1. Measurement results of the durability test.

	Category	Criterion	Resilient Channel System	Test Result	Comment
Lateral load resistance	Load cell static pressure (maximum deformation)	10 mm or less	2.12 mm	SD (Severe Duty)	Based on the BS 5234 PART 2 standard
	Load cell static pressure (residual deformation)	1 mm or less	0.46 mm		
Impact resistance	Soft body	Residual deformation less than 2 mm	0.8 mm		
	Hard body	No penetration (30 N·m)	No penetration		

3.3. Economic Efficiency Analysis

For the economic efficiency analysis, the total construction costs of the resilient channel wall, double stud wall, and concrete wall, which combined the material and construction costs, were compared as applied to an actual hotel based on their material and construction costs per unit area building. In the case of the reinforced concrete (RC) structure, which has been most widely used in the field among wet walls, it is difficult to shorten the construction period due to many tasks that are added for wall installation and the time required for concrete curing. The double stud wall also requires a long construction time because runners and studs are placed in two rows, and one more gypsum board is installed in the air space. Therefore, the construction cost of each method was estimated by calculating the actual personnel input per unit area based on the cost statements, as shown in Table 2. When this was applied to the Seoul City Hotel (S-CITY) site, the construction period reduction effect of the resilient channel wall was compared with those of the double stud gypsum board wall and concrete wall. When each wall was applied to the site, the average amount of construction per person was 2.67 m² for the resilient channel wall, 2.08 m² for the double stud wall, and 1.81 m² for the concrete wall. Based on these results, it is possible to calculate the number of days required for one person to complete construction for the entire area by dividing the total area of the partition walls between the rooms of S-CITY (2956 m²) by the daily amount of construction per person. When the number of workdays was assumed based on the input of 10 workers, the resilient channel wall was found to reduce the construction period by 31.4 d compared to the conventional double stud wall. The difference was clearer when it was compared with the wet wall. When the resilient channel wall was applied to the site, the construction period could be reduced by 52.6 d. When the material cost of each wall was calculated based on the actual quantities of input materials, the resilient wall could save costs by 13% and 21.6% compared to the double stud wall and concrete wall, respectively, because the use of runners, studs, and gypsum boards was reduced. When the construction and material costs were combined, the resilient channel wall exhibited improvement effects of 17.9% and 17.8%.

Table 2. Analysis of the construction cost. RC: reinforced concrete.

Constructability Analysis (Personnel Input per Unit Area)							
Process	Resilient Channel Wall		Double Stud Wall		RC Wall		
Installation of runners, C-studs, and other materials	Special worker	0.105	Special worker	0.150	Marking	Carpenter	0.032
	General worker	0.015	General worker	0.015	Building protection	General worker	0.004
	Subtotal	0.120	Subtotal	0.165		Construction machinery driver	0.006
Glass wool installation (24 K, 50 mm)	Interior worker	0.067	Interior worker	0.067	Concrete pouring (m ²)	Concrete worker	0.049
						General worker	0.024
Gypsum board installation	Carpenter	0.120	Carpenter	0.180	Rebar processing and assembly	Steelworker	0.071
	General worker	0.068	General worker	0.068		General worker	0.028
	Subtotal	0.188	Subtotal	0.248	Formwork installation and dismantling	Mold worker	0.230
					General worker	0.108	
Total	0.375		0.480		0.552		

3.4. Life-Cycle Cost

With the development of construction technologies, the service lives and heights of buildings are increasing. Unlike the building frames which last longer, however, interior finishing structures, such as floors, walls, and ceilings, require periodic remodeling [24]. Therefore, in the economic efficiency analysis stage, it is necessary to analyze the LCC, which includes waste disposal, long-term repair, and building maintenance costs, in addition to material and construction costs, i.e., the initial investment costs. Buildings in South Korea are rebuilt with a service life of approximately 30 years after construction, which causes problems such as wasting of resources and energy during construction as well as environmental destruction. While maintenance is difficult for the existing RC wet walls, maintenance and remodeling are easy, and sustainable development is promoted for lightweight drywalls using gypsum boards. Therefore, the LCCs of the resilient wall, double stud wall, and RC wall were calculated for a building reconstruction period of 30 years to analyze the effect of applying the resilient wall in the field. The LCC of each wall was divided into the costs before and after use. The before-use cost included material and construction costs, and the after-use cost included the demolition and waste disposal costs. Drywalls are very favorable in terms of building variability and maintenance because they can be easily dismantled compared to RC structures during remodeling and major repairs. Based on the typical wall thickness of 200 mm, the labor required for demolishing an area of 50 m² (a volume of 10 m³) was calculated and converted into the input cost. When the demolition cost was calculated based on the above contents, the demolition cost of the lightweight wall was estimated to be 32% of that of the RC wall that used little equipment. Table 3 shows the process of calculating the input costs for tearing down the lightweight and RC walls.

Table 3. Life-cycle cost of each type of wall (unit: USD; construction area: 2956 m²).

	Resilient Channel Drywall	Double Stud Drywall	Concrete Wall
Construction cost (material cost + construction cost)	221,432	262,177	259,740
Regular repair cost	Demolition cost	17,261	53,743
	Waste disposal cost	14,748	50,444
Total	253,441	296,247	363,927

RC is the waste that is generated in the largest quantities during the dismantling of a building (37%). The resilient channel wall reduces the generation of waste by replacing the conventional boundary walls between rooms mainly made of RC with drywalls that use gypsum boards, thereby contributing to the environmental load reduction and creating economic effects. To examine the economic effects caused by the construction waste reduction, the waste disposal cost per unit area was calculated for each technology. The calculation criteria for the waste disposal cost were the recent construction waste disposal costs calculated by the Korea Construction Resource Association through

a cost calculation agency registered in the Ministry of Economy and Finance. The waste generated during building dismantling was calculated mainly based on the major input materials to each wall, and subsidiary materials, such as screws, sealants, and pieces, were excluded from the list. This is because the weight and volume of the subsidiary materials represented an insignificant proportion of all the waste generated. As shown in Table 3, the LCC of each wall type, which combined the initial construction cost, periodic remodeling cost, and waste disposal cost in the building dismantling stage, was compared. When applied to a building with an area of 2956 m², the resilient channel drywall was found to reduce costs by 30.3% and 14.4% compared to the concrete and double stud drywall, respectively.

4. Discussion

Emissions of CO₂

Two key global concerns of the 21st century are global warming and environmental protection, which require the reduction of greenhouse gas emissions. Accordingly, various efforts have been made recently in the construction sector to meet low-carbon green growth initiatives, which are the basis of the national policies of Korea. From an environmental perspective, manufacturing cement clinker from limestone and chalk consumes the most energy in the construction sector [25]. The most commonly used cement is Portland cement, and 95% of its components are made of cement clinker. Clinker production is an energy-intensive process because it is produced by heating limestone to 950 °C [26]. Therefore, to reduce CO₂ emissions, it is necessary to expand the application of lightweight walls composed of gypsum boards and lightweight steel frames to replace conventional concrete walls mainly made of cement. To this end, the comprehensive evaluation of the effect of drywalls on buildings, in addition to sound insulation performance, is essential. RC structures, which are the representative wet method, emit a large amount of carbon dioxide during the material firing process. Gypsum board drywalls, however, reduce CO₂ emissions by approximately 59.3% compared to the wet method (RC structures) through the application of eco-friendly construction materials, thereby enabling sustainable development. To prove this, the CO₂ emissions of the resilient channel wall were compared with those of the conventional double stud drywall and concrete wall for an actual building. CO₂ emissions were calculated through the following procedure. First, the most representative materials for each method were classified based on the cost statements. Subsidiary materials, such as screws, pieces, and release agents, were excluded from the material list because their application amounts and CO₂ emissions are low, and thus, their evaluation was judged to be negligible.

CO₂ emissions can be calculated using the existing database [27] on the CO₂ emission intensity of each major material and the required amount of each major material per unit area presented above. In this instance, a unit conversion must be performed for items that use different units for the material amount and CO₂ emission intensity:

$$\begin{aligned} &CO_2 \text{ emissions of major materials} \\ &= \sum (\text{Quantity of a material} \times CO_2 \text{ emission intensity}) \end{aligned} \quad (6)$$

Tables 4–6 show the results of analyzing the CO₂ emissions of the three walls.

As shown in Tables 4–6, the wet wall (RC structure) exhibited the highest CO₂ emissions per unit area, followed by the existing technology (double stud method) and the resilient channel wall. In the case of the drywalls, CO₂ emissions are less than 50% compared to the wet wall, and most of them are generated through gypsum boards and glass wool. In the case of the wet wall (RC structure), the total CO₂ emissions per 1 m² are 93.9 kg-CO₂, and ready-mixed concrete represents the majority of these emissions (88.20%). The resilient channel wall emitted 38.31 kg of CO₂ per unit area and saved 55.6 kg (approximately 59%) compared to the wet wall (RC structure) and 7.3 kg (approximately 16%) compared to the double stud method, indicating its significant effect in terms of eco-friendliness. When the effect on the entire building was examined rather than on an area unit, the total area of the

walls actually used in the hotel building was 2956 m², and the resilient channel wall saved 21.6 tons of CO₂ compared to the double stud method. The difference was more obvious when compared with the concrete wall applied to the site. When the resilient channel wall was applied to the site instead of the concrete wall, the reduction in CO₂ emissions amounted to 164.4 tons (Table 7).

Table 4. Concrete wall CO₂ emissions.

Category	Unit	Required Quantity	CO ₂ Emission Intensity	CO ₂ Emissions (kg-CO ₂)	Proportion of CO ₂ Emissions (%)
Ready-mixed concrete	m ²	0.202	409.98106	82.82	88.20
Rebar	kg	24	0.39625	9.52	10.12
Euro form	m ²	2.4	0.39538	1.58	1.68
Subtotal				93.91	100

Table 5. Double stud wall CO₂ emissions.

Category	Unit	Required Quantity	CO ₂ Emission Intensity	CO ₂ Emissions (kg-CO ₂)	Proportion of CO ₂ Emissions (%)
Fireproof gypsum board	m ²	4.200	7.00714	29.43	64.52
Soundproof gypsum board	m ²	1.050	0.04867	7.36	16.13
Runner	m	1.750	0.04867	0.09	0.19
Stud	m	5.250	0.04867	0.26	0.56
Glass wool	m ²	1.100	7.71169	8.48	18.60
Subtotal				45.61	100

Source: Analysis of CO₂ emissions from apartments using cost statements and life cycle assessment (LCA).

Table 6. Resilient channel wall CO₂ emissions.

Category	Unit	Required Quantity	CO ₂ Emission Intensity	CO ₂ Emissions (kg-CO ₂)	Proportion of CO ₂ Emissions (%)
Fireproof gypsum board	m ²	4.200	7.00714	29.43	76.82
Stud	m ²	2.042	0.04867	0.10	0.26
Runner	m	0.875	0.04867	0.04	0.11
Resilient Channel	m	5.250	0.04867	0.26	0.67
Glass wool	m ²	1.100	7.71169	8.48	22.14
Subtotal				38.31	100

Source: Analysis of CO₂ emissions from apartments using cost statements and life cycle assessment (LCA).

Table 7. CO₂ emission reduction for the resilient channel structure.

Category	Reduction Compared to the Double Stud Method	Reduction Compared to the Concrete Wall
Reduction per unit area	<ul style="list-style-type: none"> ■ 16% reduction in CO₂ emissions compared to the existing technology (DSA-S) ■ 7.3 kg reduction from 45.61 to 38.31 kg-CO₂ 	<ul style="list-style-type: none"> ■ 59% reduction in CO₂ emissions compared to the wet wall (RC) ■ 55.6 kg reduction from 93.91 to 38.31 kg-CO₂
Reduction for the building	<ul style="list-style-type: none"> ■ 2956 m² × 7.3 kg/m² = 21.6-ton reduction 	<ul style="list-style-type: none"> ■ 2956 m² × 55.6 kg/m² = 164.4-ton reduction

5. Conclusions

In this study, a gypsum board drywall with resilient channels, which are an essential element for the weight reduction of high-rise buildings, was developed, and the sound insulation performance, durability, economic efficiency, CO₂ emissions, and LCC of the structure were evaluated. It was found that the developed drywall had a 3 dB higher sound insulation performance than the concrete wall, even though it was 50 mm thinner, and it had an approximately 5 dB higher sound insulation performance than the double stud wall, which has been most widely used. As the proposed wall is thin and able to secure excellent sound insulation performance, it is expected to increase economic efficiency due to an increase in applicable space when applied to buildings such as hotels, hospitals, and shopping malls.

In addition, a clip that allows resilient channels to be inserted and fixed without using screws was developed to improve the construction speed. When the clip was applied to an actual building with a wall area of 2956 m², the construction period was reduced by 52.6 and 31.4 d compared to the periods for the concrete and double stud walls, respectively. This can be a very important benefit in the future construction market where skyscrapers are gradually increasing. For skyscrapers, mass construction is essential due to a large number of walls. The existing method of using screws to fix resilient channels increases the construction cost and time because it requires at least two to three workers. The proposed method, however, can significantly contribute to a reduction in the construction cost and time because one worker can easily install the resilient channels. The method is also expected to replace concrete walls because it secured the SD grade—the highest grade in the BS 5234 Part 2 standard—in durability evaluation and can be used in all buildings.

The necessity of replacing concrete walls with gypsum board walls has been confirmed through the reduction in weight and CO₂ emissions as well as the LCC analysis results. From the perspective of CO₂ emission reduction, which is an international goal for mitigating global warming, it was found that reducing the use of concrete walls, which are mainly made of cement that generates a large amount of CO₂ in the firing process and replacing them with gypsum board walls could reduce CO₂ emissions by 59%. In the LCC analysis results focused on the initial construction cost, material cost, and periodic remodeling of structures inside a building, the gypsum board wall saved costs by 30.3% compared to the concrete wall.

The results of this study show the benefits of applying gypsum board walls to future buildings instead of concrete walls based on the results of installing such walls in an actual building. As the sample building used was a hotel, the results presented herein will be verified by applying the same analysis procedure to different building types and heights in further research.

Author Contributions: Conceptualization, K.H.K.; methodology, K.H.K.; validation, K.H.K. and J.Y.J.; formal analysis, K.H.K.; investigation, K.H.K.; writing—review and editing, K.H.K.; supervision, J.Y.J.; project administration, J.Y.J.; funding acquisition, J.Y.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Bio & Medical Technology Development Program of the National Research Foundation of Korea (NRF) and the Korea government (MSIT), grant number 2019M3E5D1A01069363.

Conflicts of Interest: The authors declare no conflict of interest.

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