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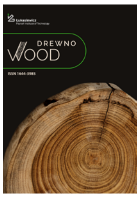

Effects of Different Technologies of Timber Ceiling on the Dynamic and Acoustic Properties of Timber Frame Prefabricated Buildings

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The natural frequency of a building is one of the main parameters affecting the dynamic and acoustic properties of the building. This study investigates the influence of two timber ceiling technologies—KVH timber and the Steico wall system—on the dynamic and acoustic properties of prefabricated timber-frame buildings. KVH is a kiln-dried, finger-jointed solid structural timber widely used in load-bearing applications, whereas the Steico wall system is a prefabricated lightweight timber panel designed for sustainable construction. Also, this paper aims to study the effect of the presence of an additional story on the dynamic and acoustic properties of timber buildings. Three different timber buildings have been taken into account. The first one is a two-story building with a KVH layer, the second one is a one-story building with a Steico wall, and the third one is a one-story building with a KVH layer. Measured fundamental natural frequencies were 42.63 Hz, 26.81 Hz, and 21.39 Hz, respectively, demonstrating clear quantitative differences between the systems. Statistical indicators, including mean values, standard deviation, and coefficients of variation (below 15%), confirm acceptable repeatability. The stiffness of those buildings has been evaluated as well. It was concluded from this study that the ceilings composed of the KVH layer have better acoustic properties than the ceilings composed of the Steico wall. Also, it was concluded that the presence of an additional story worsens the acoustic properties of the ceiling and increases the stiffness of the building, affecting the dynamic properties of the timber building.

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Introduction

The use of lightweight timber buildings is rapidly growing worldwide, enhanced by many factors, including the Kyoto Protocol (De Geetere & Ingelaere, 2014). Preferring lightweight timber buildings over the traditional heavyweight concrete and steel buildings is referred to as several factors, such as the fact that the lightweight timber buildings are renewable and environmentally friendly. Wood is a renewable and low-carbon construction material, making it a key component of sustainable building strategies. Timber construction is gaining popularity due to its renewable nature, lower CO2 emissions compared to concrete and steel, and favorable performance in seismic regions owing to its lightweight and flexible properties. In seismic regions such as Japan, New Zealand, and the USA, timber buildings perform well due to their low mass and ductility, which reduce seismic demand and energy dissipation requirements. Also, from an engineering point of view, since timber buildings are prefabricated, it will be easier to construct, permitting

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complex architectural plans and ensuring minimal cost and waste. The growth of the use of timber buildings has been experienced in different parts of the world, such as Japan (Ryu et al., 2011), New Zealand (Chung et al., 2010), and Europe (Ljunggren & Ågren, 2011). The development of engineering codes has also led to the growth of the use of timber buildings worldwide.

Even though the use of timber buildings has a lot of advantages over traditional heavyweight buildings, the use of timber buildings has come with some problems as well. The impact noise is one of the biggest challenges of timber buildings since the impact noise is considered the most oppressive for the inhabitants (Ljunggren & Simmons, 2022; Ljunggren et al., 2014; Ljunggren et al., 2017). Timber floors have low sound insulations including human footsteps, for instance (Amiryarahmadi et al., 2016; Homb et al., 2017; Zhang et al., 2020). Indeed, lightweight timber buildings do not have the best acoustic properties due to the fact that the traditional methods that are used for sound isolation in heavyweight buildings are not as efficient in lightweight timber buildings as they are in heavyweight buildings (Caniato et al., 2017). In traditional heavyweight buildings, high-density solutions are often applied to reduce the impact sound pressure level. Another reason is referred to the fact that the timber buildings are too varied. From the same raw materials, totally different timber buildings with totally different properties can be produced based on the manufacturer, company, or designer. This includes the method to be fastened, including the location, length, shape, and number of the screws. This makes it not possible to predict the acoustic properties or the sound propagation. The propagation of acoustic waves in timber is influenced by density, stiffness, board layering, and structural connections, which affect impact sound transmission and vibration characteristics. To predict the impact of sound propagation, the input data, such as the material characteristics (orthotropic, anisotropic, and isotropic), complex structural systems, local deformations, mid-frequency transmission over flanks, and low-frequency transmission, should be taken into account, which is apparently hard to achieve (Caniato et al., 2021; Jayalath et al., 2021; Nasir et al., 2022). Moreover, the variation in dataset/sample group in the mechanical properties of timber is considered another challenge for the acoustic response (Füssl et al., 2016; Lim et al., 2023; Persson & Flodén, 2019; Sepahvand et al., 2015). Indeed, the uncertainty in the acoustic performance is lower in prefabricated timber buildings compared to the on-site constructed buildings (Öqvist et al., 2012). Caniato et al. (2022) analyzed the theoretical methods for studying the acoustic behavior of complex structures with their advantages and disadvantages. The issue of the impact sound in timber buildings is more evident in low-frequency range vibrations with less than 100 Hz (Gibson et al., 2022; Olsson & Linderholt, 2018, 2020, 2021; Rindel et al., 20–22 June, 2016) and reaching satisfactory acoustic properties for low-frequency range vibrations with 20–120 Hz is more challenging (Bodlund, 1985; Gerretsen, 1976; Olynyk & Northwood, 1968; Qian et al., 2019). Considering the fact that the use of lightweight timber buildings is new, there are still few studies that have taken into account the acoustic performance and the methods to enhance the acoustic properties. Caniato et al. (2017) performed measurements on a full-scale timber building to evaluate the frequency of the impact noise of bare floors. Yang et al. (2021) studied the acoustic properties of cross-laminated timber panels. It was found that the elastic modulus, shear modulus, density, and damping loss factor have a significant influence on sound transmission loss. Ljunggren (2023) suggested efficient methods to improve the acoustic properties of cross-laminated timber panels. Bella and Mitrovic (2020) provided an in-depth review of the acoustic properties of cross-laminated timber. Increasing the height of cross-laminated timber buildings will lead to higher sound transmission, which means lower sound insulation (Nilsson et al., 2023). Chen et al. (2022) suggested techniques to improve the sound absorption performance of timber walls. Nurzyński and Nowotny (2023) studied the sound insulation of floors with different insulation layers by conducting experiments on composite panels. Ljunggren and Ågren (2011) suggested adding additional mass and damping to the floor as a method to improve the acoustic performance of the floor, such as adding extra board layer(s), elastic glue between floor boards, and a floating floor.

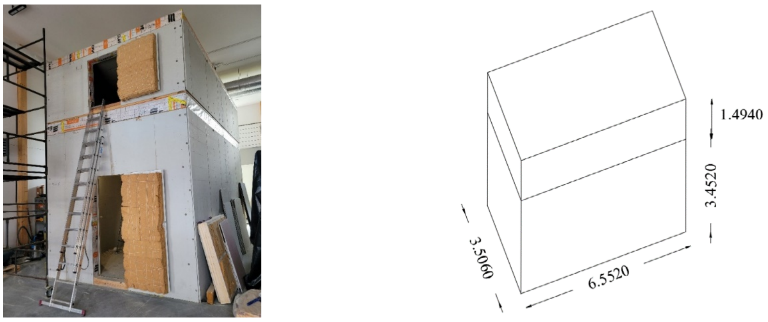
On the other side, several researchers have focused on the prediction of the dynamic properties of timber buildings and the factors that influence them. Szczepański et al. (2022) studied the effect of the size and location of openings in the wooden frame walls under dynamic loadings. It was found that the effect of the size and location of the openings on the natural frequency is significant, where the difference between the natural frequency for the wall with and without an opening can reach 30% (the effects of the location are more significant than the effects of the size of the opening). Ellis and Bougard (2001) compared the stiffness of bare timber frames to the stiffness of a complete building. Similar to the acoustic properties, the construction procedure has a significant effect on the dynamic properties of timber buildings. The on-site conditions have a significant influence on the natural frequency, mode shapes, and damping ratio, where the key impact is on the damping ratio (Jarnerö et al., 2015). The construction quality significantly influences the collapse fragility of timber buildings (Christovasilis et al., 2009). Also, the mass of the building impacts the fundamental frequency for timber buildings, which means accurate estimation of the mass is necessary for accurate dynamic modelling of timber buildings (Mugabo et al., 2019). Rijal (2016) investigated the dynamic properties of long-span timber floors (beams), including the natural frequency, mode shapes, and damping ratio. Moreover, environmental factors such as the moisture content significantly affect the long-term performance of timber buildings, as it was found that there is a significant correlation between the moisture content and the natural frequency for the timber building (Larsson et al., 2022). Indeed, methods to improve the dynamic properties of timber buildings have been suggested and studied in the past. Szczepański et al. (2016, 2017, 2019, 2020) and Migda et al. (2019) studied the use of polyurethane foam and mineral wool as thermal isolation and compared their effects on the dynamic properties of timber buildings. It was found that the use of polyurethane foam as thermal isolation leads to a substantial increase in stiffness and damping properties, as compared to the use of mineral wool. When the former one was used, the panel passed all the test while when the latter was used, the panel experienced significant damage.

Despite the advantages of timber buildings, acoustic comfort—particularly impact sound transmission—remains one of the main challenges of lightweight timber buildings. KVH timber and Steico wall systems are increasingly used in prefabricated buildings; however, their comparative influence on vibration and acoustic performance has not been sufficiently investigated. The research hypothesis of this study is that different timber ceiling technologies and the presence of an additional story significantly affect the natural frequency, stiffness, and consequently the acoustic and dynamic performance of timber buildings. Also, the previously described studies have suggested several methods to enhance the acoustic or dynamic performance of timber buildings. However, these studies didn't consider the influence of the type of timber boards/layers on the acoustic and dynamic properties of the timber building. Therefore, this paper aims to study the effect of two different kinds of timber boards/layers on the acoustic and dynamic properties of timber buildings. Also, this paper aims to study the influence of the presence of an additional story on the acoustic and dynamic properties of timber buildings. Two kinds of timber boards/layers have been taken into account, which are KVH and Steico wall. KVH is a kiln-dried, finger-jointed solid structural timber, while the Steico wall system is a prefabricated timber panel system designed for lightweight building construction. KVH (Konstruktionsvollholz) is not a single trade brand but a standardized category of structural solid timber manufactured by various certified European producers in accordance with EN 15497, ensuring defined strength, moisture content, and dimensional stability. Moreover, the Steico wall system represents an industrialized timber-based building envelope solution combining structural timber framing with wood-fiber insulation layers, designed to enhance thermal, acoustic, and hygrothermal performance in lightweight constructions.

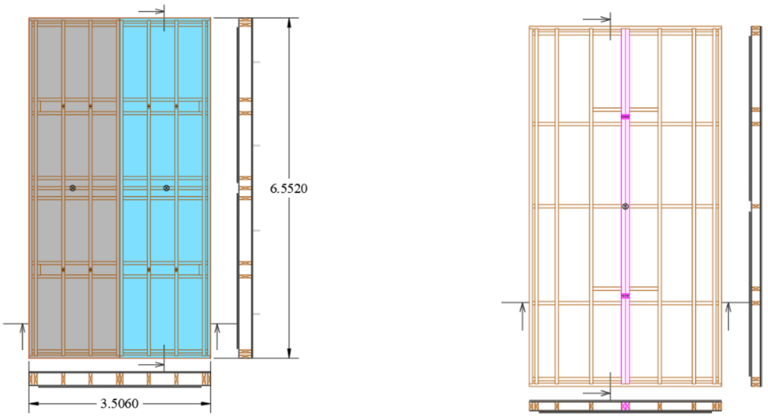
The influence of these kinds of boards/layers on the acoustic and dynamic properties of timber buildings has been studied. This has been done by studying the effect of these types of boards on the natural frequency of the ceilings of timber buildings. Three different timber buildings have been taken into account. The ceiling of each building is composed of one timber board type from the two timber board types mentioned above (KVH and Steico wall). Two buildings with one story and two stories have a ceiling composed of a KVH layer, while the third building is a one-story building with a ceiling composed of a Steico wall. Experimental measurements have been performed to evaluate the natural frequency for the ceiling of each building, and hence, a clearer view of the effect of these types of timber boards, as well as the presence of additional stories, on the acoustic and dynamic properties of the ceilings of these three timber buildings. The frequency of the ceiling of every building is discussed and compared. The difference between the frequencies of the ceilings of the considered buildings is attributed to multiple reasons, including the layer types. Since the frequency of the ceiling affects the acoustic properties and dynamic response, discussions on the influence of the difference in frequencies on the acoustic and dynamic properties are presented. Conclusions on the influence of the layer types that have different frequencies on the acoustic and dynamic properties are presented. The two-story building was selected to study the effect of an additional story and increased structural stiffness, while the single-story buildings allow comparison between KVH and Steico systems in lightweight structures. This study differs from prior works by comparing the impact of two specific timber ceiling technologies (KVH and Steico) on both dynamic and acoustic properties in one- and two-story prefabricated buildings, providing experimental evidence for material choice and building configuration effects.

Methodology of the experiments

In the experiments, three buildings have been taken into account. Building 1 is a two-story building, while Buildings 2 and 3 are one-story buildings. The 3D view, plan view, sketches, and dimensions of Buildings 1, 2, and 3 are presented in Figs. 1, 2, and 3, respectively. Table 1 presents the mass of the ceilings of the three

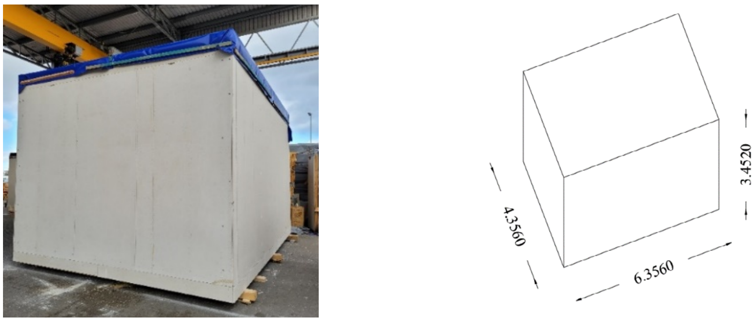


(a) real view (b) dimensions (m)

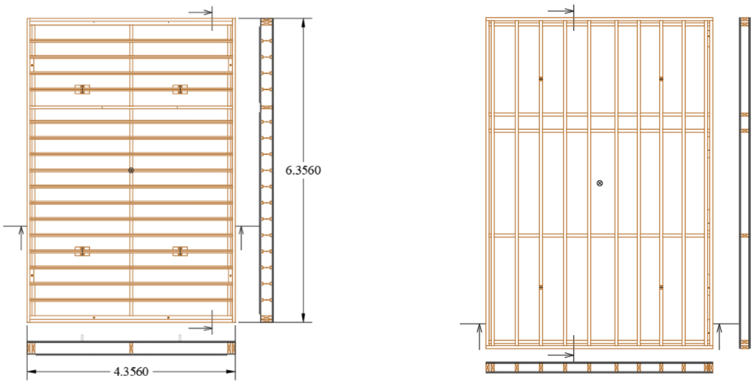


(c) plan view for the ceiling of the first floor (level 1) (m) (d) plan view for the ceiling of the second floor (level 2)

Fig. 1. Building 1



(a) real view (b) dimensions (m)

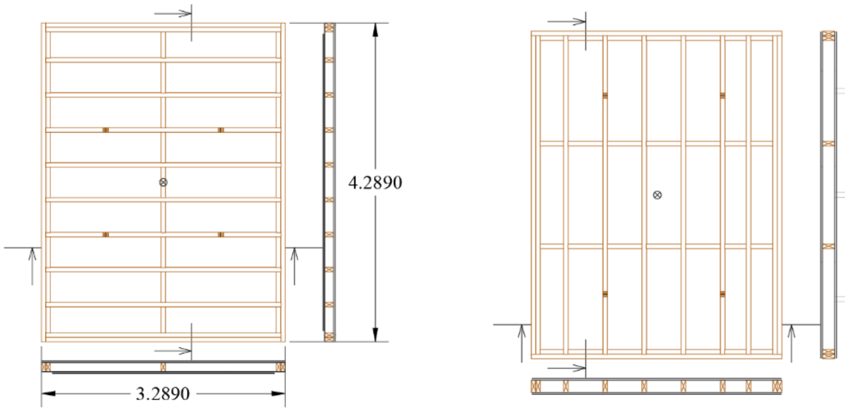


(c) plan view for the ceiling of the first floor (level 1) (m) (d) plan view for the ground floor (level 0)

Fig. 2. Building 2

(a) real view

(b) dimensions (m)



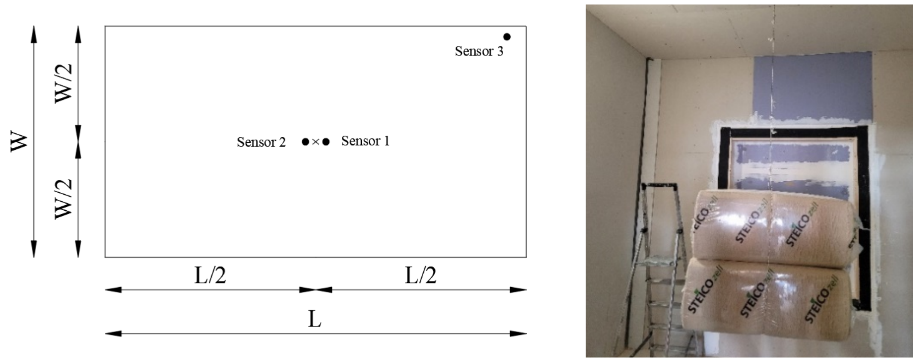
(c) plan view for the ceiling of the first floor (level 1) (m)

(d) plan view for the ground floor (level 0)

Fig. 3. Building 3

(a) Quantum machine and sensors

(b) Sensors location



(c) Plan view of the sensors location

(d) The rope and the connected mass

Fig. 4. Measurement system

Table 1. Properties of the considered buildings (Height measured from the ground)

Building	Ceiling	Length (m)	Width (m)	Height (m)	Mass (kg)
Building 1	Ceiling 1	6.5520	3.5060	3.452	825.163
	Ceiling 2			4.946	838.168
Building 2	Ceiling 1	6.3560	4.3560	3.452	1573.702
Building 3	Ceiling 1	4.2890	3.2890	2.632	684.432

Table 2. The layers of the ceiling of the first floor of the considered buildings

Layer	Building 1	Building 2	Building 3
1	OSB 22 mm	OSB 22 mm	OSB 22 mm
2	KVH (240 mm)	Steico wall	KVH (120 mm)
3	Membrane	Membrane	Membrane
4	MFP board 12 mm	MFP board 12 mm	MFP board 12 mm
5	Siniat board 12.5 mm	-	Siniat board 12.5 mm

buildings. Indeed, Table 2 presents the layers of the ceiling of the first floor of the three considered buildings. As can be seen in Table 2, the ceiling is composed of 5 layers denoted as layers 1, 2, 3, 4, and 5. It can be seen that layers 1 (Oriented strand board (OSB) of 22 mm), 3 (Membrane), and 4 (Multi-Function Panel (MFP) of 12 mm) are the same among all buildings. The difference in the ceiling of these three buildings is in layers 2 and 5. In layer 2, two different types of layers have been used, which are KVH for the ceilings of Buildings 1 and 3, while Steico wall has been used for the ceiling of Building 2. Indeed, concerning layer 5, a Siniat board with 12.5 mm thickness has been added for the ceiling of Buildings 1 and 3, while no Siniat board has been added for the ceiling of Building 2. The selected configurations allow isolation of material effects (KVH vs. Steico) and structural effects (single-story vs. two-story). The wood raw materials were sourced from certified suppliers: KVH timber – supplied by a certified CE-marked European manufacturer; Steico wall panels – manufactured by Steico S.A., Czarnków, Poland; OSB (22 mm) – CEcertified OSB/3 producer; and MFP (12 mm) – CEcertified European supplier. Three accelerometers recorded vibrations at the middle and corner positions, and the FFT method was used. The FFT has been performed using SeismoSignal software following established experimental vibration testing procedures reported in the literature (Wang et al. 2025; Wu et al. 2026; Zhu et al. 2023; Yan et al. 2026; Yan et al., 2026; Bödeker et al. 2025). Seven repetitions were conducted per building to obtain sample statistics. The experiments have been performed at the laboratory of Ekoinbud, a timber company located in Gdańsk, Poland. The measurement system is presented in Fig. 4. The experiments were performed by hanging a weight of 30 kg using a rope in the middle of the ceiling. Then, the rope was cut, causing a vibration in the ceiling. The acceleration of the vibration has been measured and recorded using the quantum machine and Catman software (Fig. 4a). Three sensors have been used in the study. Two sensors are connected to the middle of the ceiling, while the third is connected to one of the corners (Figs. 4b; 4c). All this system is set before cutting the rope. Two bags are connected to the rope with 15 kg each (Fig. 4d). After the rope is cut, the vertical acceleration response of the ceiling is measured, which represents the free vibration response. This experiment has been performed 7 times for every building. As a result of this experiment, we obtained the acceleration time history 7 times for every building using 3 sensors (3 buildings* 3 sensors * 7 times). After that, the spectrum analysis was performed using Fourier analysis (FFT – Fast Fourier Transform) on the collected data. In this method, the time signal is converted into a frequency signal, which shows the natural frequency for the recorded signal. The natural frequency considered in this paper and used for comparison is the maximum natural frequency obtained for every building among all vibrations and sensors. The experiments were conducted using an HBM QuantumX data acquisition system connected to three factory-calibrated piezoelectric accelerometers (100 mV/g). The data were recorded at a sampling frequency of 1200 Hz with anti-aliasing filtering. A 30 kg drop mass was used as the excitation source, and each test was repeated seven times for every building in accordance with Eurocode recommendations. The natural frequencies were then determined using FFT analysis. The 30 kg mass represents a typical load; sensors were placed at the middle and corner positions, FFT analysis followed standardized procedures, and seven repetitions ensured repeatability. Statistical evaluation of the experimental results was conducted to assess the repeatability and reliability of the measured natural frequencies. For each building, seven repeated tests were performed, and descriptive statistical parameters were calculated, including minimum value, maximum value, mean value, standard deviation, and coefficient of variation (CV). The coefficient of variation, defined as the ratio of the standard deviation to the mean value, was used as an indicator of data dispersion and measurement stability. According to commonly accepted engineering practice, a coefficient of variation below 10% indicates low variability, while values between 10% and 20% indicate moderate variability. This statistical approach allows for an objective comparison of the vibration characteristics of the tested ceiling systems and supports the reliability of the experimental results.

Results and discussions

The frequency for every building has been obtained using the FFT method as mentioned in the previous section. The obtained frequencies for the ceilings of Buildings 1, 2, and 3 for every vibration and sensor are listed in Tables 3, 4, and 5, respectively. The comparison of the frequency for these buildings for all vibrations and sensors is also presented in Fig. 5 (the x-axis is represented as "i-j" where "i" corresponds to the vibration number and "j" corresponds to the sensor number, i.e., "1-3" corresponds to vibration number 1 recorded by sensor 3). It can be seen that the calculated frequencies for the ceiling of Building 1 are the highest, followed by the frequencies for the ceiling of Building 2, while the ceiling of Building 3 has the lowest frequency. The natural frequency considered in this paper and used for comparison is the maximum natural frequency obtained for every building among all vibrations and sensors. Differences in natural frequencies are attributed to material types, layer configurations, ceiling mass, and the presence of additional story, which

Table 3. Frequency for the ceiling of the first floor of Building 1

Vibration	Sensor	Frequency (Hz)
1	1	41.31
	2	41.31
	3	37.20
2	1	41.38
	2	41.16
	3	36.25
3	1	42.33
	2	42.33
	3	26.95
4	1	42.19
	2	42.19
	3	39.99
5	1	41.09
	2	41.09
	3	38.45
6	1	42.63
	2	42.63
	3	39.99
7	1	41.67
	2	41.67
	3	39.55
Maximum Frequency (Hz)		42.63

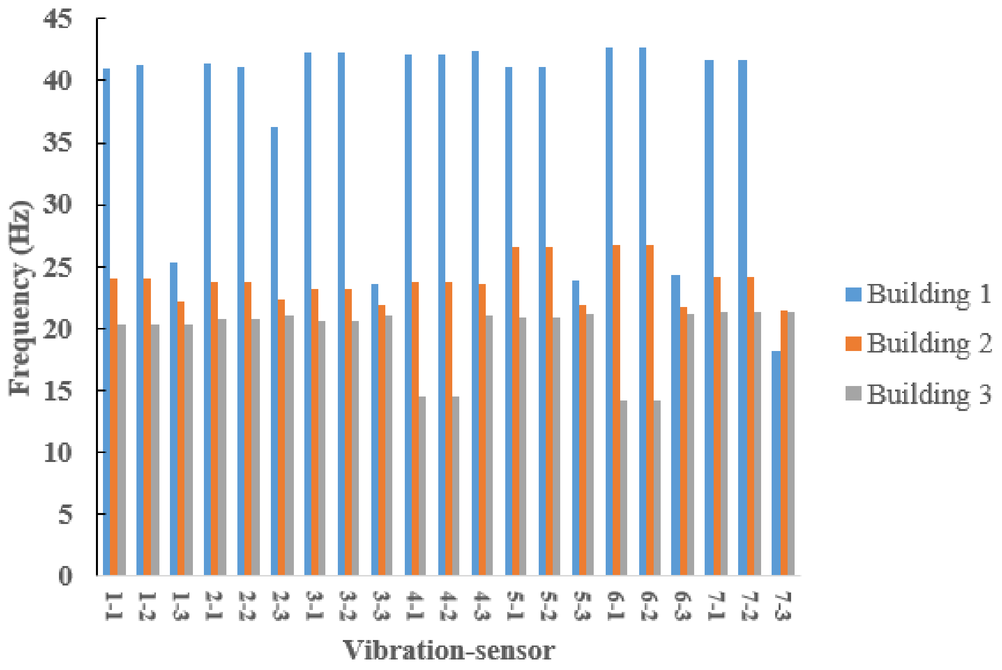


Fig. 5. Comparison between the calculated frequencies for the ceilings of the first floor of Buildings 1, 2 and 3 for all vibrations and sensors

Table 4. Frequency for the ceiling of Building 2

Vibration	Sensor	Frequency (Hz)
1	1	24.02
	2	24.02
	3	22.12
2	1	23.73
	2	23.73
	3	22.27
3	1	23.14
	2	23.14
	3	21.97
4	1	23.73
	2	23.73
	3	23.58
5	1	26.66
	2	26.66
	3	21.97
6	1	26.81
	2	26.81
	3	21.83
7	1	24.17
	2	24.17
	3	21.53
Maximum Frequency (Hz)		26.81

Table 5. Frequency for the ceiling of Building 3

Vibration	Sensor	Frequency (Hz)
1	1	20.36
	2	20.36
	3	20.36
2	1	20.80
	2	20.80
	3	21.09
3	1	20.65
	2	20.65
	3	21.09
4	1	14.50
	2	14.50
	3	21.09
5	1	20.95
	2	20.95
	3	21.24
6	1	14.21
	2	14.21
	3	21.24
7	1	21.39
	2	21.39
	3	21.39
Maximum Frequency (Hz)		21.39

provides vertical support, increasing stiffness and reducing vibration amplitudes. The natural frequency for Buildings 1, 2, and 3 is 42.63 Hz, 26.81 Hz, and 21.39 Hz, respectively. The minimum, maximum, and mean frequency of each building are presented in Table 6. The standard deviation and coefficient of correlation are also presented in Table 6. The coefficients of correlation for Buildings 1, 2, and 3 are 8.67%, 7.07%, and 13.55%. The coefficient of correlation for Buildings 1 and 2 is less than 10%, which means low variability. The coefficient of correlation for Building 3 is between 10–20% which means moderate variability. Therefore, the results for the frequency of the three buildings have acceptable variability. The ceiling of Building 1 has the highest natural frequency, followed by the ceiling of Building 2, while the ceiling of Building 3 has the lowest natural frequency. Higher frequency leads to sharper sounds. This means that lower frequency means better acoustic properties. Thus, by comparing the ceilings of Buildings 2 and 3, it can be said that the ceiling of Building 3 has better acoustic properties than the ceiling of Building 2, as it has a smaller natural frequency. Since the ceilings of Buildings 2 and 3 are made from different layers as described in the previous section, the previous observations can be attributed to the construction layer type. Since the ceiling of Building 3 is made from KVH while Building 2 is made from the Steico wall, it can be said that the KVH leads to better acoustic properties than the Steico wall. This observation can also be attributed to the presence of the Siniat board, and it can be said that the presence of an additional Siniat board has led to better acoustic properties. Moreover, by comparing the ceilings of Buildings 1 and 3, it can be said that the ceiling of Building 3 has better acoustic properties than the ceiling of Building 1. The ceilings of Buildings 1 and 3 are composed of the same types of layers, but Building 1 is a two-story building and Building 3 is a one-story building. Because of that, it can be said that the presence of an additional story worsens the acoustic properties of timber buildings. The experimentally obtained natural frequencies indicate that the two-story KVH building exhibits the highest frequency, followed by the one-story Steico system and the one-story KVH

Table 6. Descriptive Statistics of Buildings Frequencies: Minimum, Maximum, Mean, Standard Deviation, and Correlation

Building	Minimum frequency (Hz)	Maximum frequency (Hz)	Mean	Standard deviation	Coefficient of variation (%)
1	26.95	42.63	40.16	3.49	8.68
2	21.53	26.81	23.80	1.68	7.07
3	14.21	21.39	19.68	2.67	13.55

Table 7. Dynamic properties of the ceiling of the considered buildings

Building	Natural frequency (Hz)	Approximate stiffness (N/m)*10^6
1	42.63	119.36
2	26.81	44.66
3	21.39	12.36

system. Statistical indicators, including mean values, standard deviation, and coefficients of variation (below 15%), confirm acceptable repeatability. Qualitative construction factors such as fastening methods, layer continuity, and material uniformity also contribute to the observed differences. The calculated coefficients of variation for the natural frequencies ranged from 7.07% to 13.55%, indicating low to moderate variability of the experimental data. These values confirm that the observed differences in natural frequencies between the investigated ceiling systems are not random but result from structural configuration, material type, and building height. The relatively low dispersion of results supports the robustness of the experimental procedure and validates the comparative analysis presented in this study. It should be noted that, apart from material type and structural layout, qualitative factors related to construction technology may influence the dynamic response of timber ceilings. These include the degree of prefabrication, execution accuracy, connection stiffness, and material homogeneity. In the tested buildings, all ceiling systems were prefabricated under controlled factory conditions, which limited construction variability and reduced uncertainties related to workmanship. Therefore, the observed differences in natural frequencies can be primarily attributed to the ceiling system configuration and material composition.

Indeed, the dynamic properties, including the natural frequency and the approximate stiffness, are presented in Table 7. The approximate stiffness has been calculated using Equation (1) based on the frequency evaluated from the experiments and the mass of the ceilings presented in Table 1. The total mass is used instead of the generalized modal mass. For a given mode shape, the ceiling (total mass) of a structure does not oscillate with the same amplitude. However, the total mass is used as an approximation. Using total ceiling mass for stiffness estimation is an approximation; localized modal mass would yield more accurate stiffness, but trends and relative comparisons remain valid. It can be seen from Table 7 that Building 1 has the highest stiffness, followed by Building 2, while Building 3 has the lowest stiffness. This refers to the fact that Building 1 has the highest frequency and mass. It was shown in some studies that stiff structures have better dynamic properties and are less affected by vibrations as compared to less stiff and flexible structures (Maison & Kasai, 1992; Miari et al., 2019; Mouzakis & Papadrakakis, 2004). Also, the vertical stiffness leads to better dynamic properties since, as the building has higher vertical stiffness, it has a higher ability to resist the horizontal shear forces. Moreover, several studies focused on the influence of vertical irregularities and vertical stiffness on the seismic response of buildings (Mohamed Nazri et al., 2019; Resmitha Rani Antony & Pillai, 2016). It was concluded that higher vertical irregularities (which means lower vertical stiffness) lead to poorer seismic performance of buildings. Because of that, it can be said that Building 1 has better dynamic properties than Buildings 2 and 3, as it is stiffer than the other two buildings. Also, Building 3 has the worst dynamic properties compared to the other two buildings, as it has the lowest stiffness. The ceilings of Buildings 1 and 3 are composed of the same types of layers, but Building 1 is a two-story building and Building 3 is a one-story building. Because of that, it can be said that the presence of an additional story improves the dynamic properties of timber buildings. This is because of the additional story and the walls of the additional story. The walls act as supports on the ceiling of the first floor. Hence, those supports make the ceiling stiffer.

Comparing the acoustic and dynamic properties of the considered buildings, it can be seen that Building 3 has the best acoustic properties and the worst dynamic properties (in terms of stiffness), while Building 1 has the worst acoustic properties and the best dynamic properties (in terms of stiffness). Thus, a new technology has to be developed to make sure both better acoustic and dynamic properties are attained. However, when considering the ones described in this paper, the choice can be made based on priority. For instance, in seismic zone areas, the dynamic properties are more important, while in the non-seismic areas, the acoustic properties are more important. It should be noted that the difference in the natural frequencies and stiffness for the ceilings of the considered buildings is not only because of the types of board layers. Other factors have affected the natural frequencies of the ceilings of the considered buildings, such as the dimensions of the ceilings. It should also be noted that the quality of construction, including fastening methods, material uniformity, and panel assembly, influences stiffness and acoustic performance.

$$k = 4\pi^2 f^2 m \qquad (1)$$

where k is the stiffness (N/m), f is the frequency (Hz), and m is the mass (kg).

Conclusions

In this paper, the effect of two different kinds of timber boards on the acoustic and dynamic properties of timber buildings has been studied. Also, the influence of the presence of an additional story on the acoustic and dynamic properties of timber buildings has been investigated. Two kinds of timber boards have been taken into account, which are KVH and Steico wall. The influence of these kinds of boards on the acoustic and dynamic properties of timber buildings has been studied by examining the effect of these two types of timber boards on the natural frequency and stiffness of the ceiling of timber buildings. Three different timber buildings have been compared. Two buildings with one and two stories have ceilings composed of a KVH layer, while the third building is a one-story building with a ceiling composed of a Steico wall. Experimental measurements have been performed to evaluate the natural frequency of the ceiling of each building. It was concluded that the ceilings composed of the KVH layer have better acoustic properties than the ceilings composed of the Steico wall. Also, it was noticed that the presence of an additional story worsens the acoustic properties of the ceiling and increases the stiffness of the building, affecting the dynamic properties of the timber building. The experimental results showed that the maximum natural frequencies of the investigated ceilings were 42.63 Hz for the two-story KVH building, 26.81 Hz for the one-story Steico wall building, and 21.39 Hz for the one-story KVH building. These values demonstrate that ceiling systems based on KVH timber exhibit lower natural frequencies and improved acoustic performance compared to Steico wall systems in single-story buildings. The presence of an additional story increased the natural frequency by approximately 99% compared to the single-story KVH building, indicating a significant increase in structural stiffness due to additional vertical support provided by the upper-story walls. The presence of an additional story resulted in an increase in ceiling stiffness from 12.36 MN/m (single-story) to 119.36 MN/m (two-story), indicating strong structural interaction between the ceiling and the upper-story walls. From an acoustic perspective, lower natural frequencies observed in single-story systems suggest more favorable impact sound behavior, while higher stiffness improves dynamic performance. These quantitative findings clearly demonstrate the trade-off between acoustic comfort and structural stiffness in timber ceiling systems. This increase in stiffness was accompanied by less favorable acoustic behavior, as higher natural frequencies correspond to sharper sound perception. Statistical analysis confirmed acceptable repeatability of the measurements, with coefficients of variation ranging from 7.07% to 13.55%. These values indicate low to moderate variability and support the reliability of the experimental findings. Overall, KVH ceiling systems demonstrated better acoustic performance, while multi-story configurations improved dynamic stiffness. The results highlight a trade-off between acoustic and dynamic performance, suggesting that ceiling technology selection should depend on design priorities such as seismic resistance or acoustic comfort. Due to the limited number of tested buildings, the conclusions are restricted to the investigated configurations. Further studies involving a larger sample size and additional construction technologies are recommended to generalize the findings.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

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