
Enhancing the understanding of design for seismic resilience as part of an architectural education

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ABSTRACT

Seismic-resilient design is an important competency for architectural education in seismically active regions. However, it is often taught through generalised theory or code-based guidance, which students find difficult to understand and translate into design. This paper presents a series of structured pedagogical experiments investigating the effectiveness of combining a small-scale shaking table with MOLA construction kits as an experiential visual learning tool. This study is part of broader research investigating complementary seismic learning tools.

The study was conducted with second-year undergraduate architecture students at the School of Architecture, Victoria University of Wellington, alongside a course on structure. Students constructed three MOLA-based models representing the different lateral-resisting systems. These models were then subjected to controlled seismic simulations on a shaking table, allowing observation of structural performance, deformation patterns and failure modes. A mixed-methods evaluation framework was used, combining pre- and post-experiment questionnaires, to assess the learning outcomes. Results indicate improved understanding of seismic design principles and increased awareness of the impact architectural design may have on a building's performance under seismic loading. In contrast, the students' confidence in integrating seismic knowledge into architectural practice remained limited.

The paper argues that hands-on experimentation provides a valuable complement to lectures, instructional videos and digital analysis tools in architectural education.

1 INTRODUCTION AND PROBLEM FRAMING

Seismic resilience is a critical concern for the built environment in seismically active regions such as New Zealand (NZSEE, 2024). In architectural education, students are expected to understand how design decisions affect seismic performance (Morales-Beltran & Yildiz, 2020) rather than rely on abstract rules. This raises the concern that the challenges lie not only in the study content but also in how it is taught. Recent efforts to address this gap have focused on digital simulation, virtual reality (VR), and instructional videos. Studies by Adnin et al. (2025) demonstrate that these tools can enhance the visualisation and understanding of complex structural behaviour. Karadag & Canakcioglu (2024) warn that such tools may position students as passive observers, limiting their opportunities to test alternatives and learn through failure.

Experiential learning offers a different perspective on learning. Kolb (2015) argues that students gain a better grasp of concepts when they test ideas and reflect on the outcomes. Yet, physical experimentation remains underused in many architectural programmes despite its benefits (Abdelhady & Farid, 2018).

2 PEDAGOGICAL BACKGROUND

2.1 Seismic-Resilient Design in Architectural Education

The role of architects in seismic resilience has been widely recognised, especially in design decisions that shape structural configuration, load distribution, and spatial organisation. Charleson (1997) argues that decisions made during conceptual design stages would greatly impact a building's earthquake response. Similarly, Kam & Pampanin (2011) emphasised that seismic resilience depends not only on engineers' calculations but also on choices of systems, regularity, and detailing that either support or undermine structural performance.

2.2 Experiential and Hands-on Learning in Seismic Education

Experiential learning has been suggested as an effective approach to addressing these challenges, particularly through physical modelling and shaking table experiments (Karadag & Canakcioglu, 2024). Dyke et al. (2000) argue that shaking tables allow students to experience motion, deformation, and failure directly, making seismic behaviour more relatable to actual structures. Similarly, Karadag & Canakcioglu (2024) report improved conceptual knowledge after exposure to structural failure under controlled shaking.

The way the model is built shapes students' learning outcomes (Abdelhady & Farid, 2018). They found that students who constructed their own models showed about 18% higher understanding than those who received instruction only in lecture halls. To reduce fabrication variability and standardise the model geometry, recent research advocates using modular construction kits. Bijelica et al. (2025) note that when the MOLA construction kits were integrated into shaking table demonstrations, mean understanding scores increased from 2.72 to 4.21.

2.3 Disciplinary Context and Limitations

These learning outcomes from experiential seismic education vary across disciplines. Engineering students tend to demonstrate strong quantitative competencies, whereas architecture students show greater improvement in qualitative understanding and confidence in relating seismic behaviour to design (Bijelića et al., 2025; Karadag & Canakcioglu, 2024). This reflects the goals of architectural education, in which seismic performance must be considered alongside spatial, aesthetic, and functional concerns.

Experiential interventions also depend on prior knowledge or experience. Second-year architecture students are particularly suitable, as they are beginning to incorporate structural thinking into design. However,

seismic education is often delivered through an engineering-oriented pedagogy, in which theory, static representations, and code compliance are dominant (Morales-Beltran & Yildiz, 2020). This misalignment suggests a pedagogical gap rather than a lack of technical content.

2.4 Identified Research Gaps and Limitations in Existing Studies

Although interest in experiential seismic education is growing, important gaps remain, particularly in architectural education. Existing studies often prioritise engineering learning and technical performance (Charleson, 2018), with more limited attention to how architecture students understand structural behaviour and relate it to design. In addition, scaled physical models cannot fully replicate real structural behaviour, yet only a few studies consider whether students recognise these limitations or how such simplifications may influence their understanding (Morales-Beltran & Yildiz, 2020).

3 STUDY DESIGN AND EXPERIMENT SETUP

The study used a mixed-methods design (Creswell & Creswell, 2017) to investigate how shaking table experiments assist architecture students in understanding the seismic behaviour of structural systems and expanding their knowledge of disaster resilience (Dyke et al., 2000).

3.1 Study Context and Participants

The research was undertaken with second-year students enrolled in the architecture programme at Victoria University of Wellington during September to October 2025. The simulation involved 31 participants, organised into 6 groups of 4 to 6 students. These group sessions ensured consistent facilitation and manageable hands-on participation (Kolb, 2015). All survey responses were treated as confidential, and participants were assigned unique identification codes (Creswell & Creswell, 2017), P1–P31, for data analysis and reporting.

3.2 Experimental Design

The shaking table was coupled with MOLA construction kits to standardise member sizes, joint behaviour, and construction logic across groups, thereby reducing variability (Mojidra et al., 2025). This method addresses criticisms of previous studies that were affected due to inconsistencies in fabrication quality. Each group developed three structural models using MOLA kits: a moment-resisting frame, a braced frame, and a shear wall system. Group members were assigned construction tasks, providing opportunities to better understand the structural systems (Abdelhady & Farid, 2018).

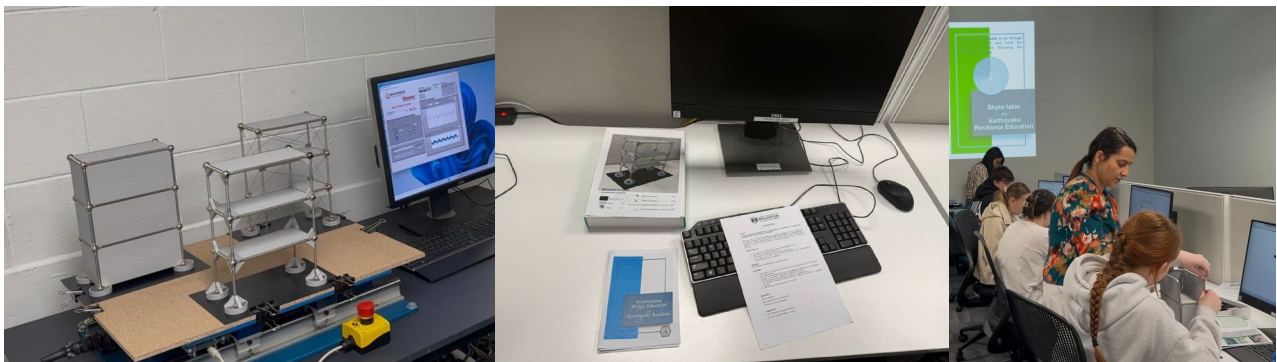


Figure 1: Three models on the same shaking table; materials and instruction book ready for participants

All three models were placed on the shaking table simultaneously under the same ground-motion conditions as in Figure 1. The shaking intensity was increased progressively to observe the initial response, structural resistance, and subsequent failure. The shaking protocol and setup remained constant throughout all sessions, ensuring that differences in behaviour reflected structural configuration rather than the testing variability (Creswell & Creswell, 2017).

3.3 Data Collection and Analysis

A mixed-methods design combining open-ended questions and Likert-scale ratings was used to collect data. Pre- and post-experiment questionnaires assessed changes in conceptual understanding and confidence in seismic design. Participants were requested to complete the pre-test survey to record their views and prior familiarity with the shaking table and disaster resilience. After the simulation, they were again asked to express their views and new insights. Data were collected through Qualtrics and analysed in Microsoft Excel.

4 KEY FINDINGS

The findings are derived from the five-point Likert-scale questionnaire and students' open-ended responses. The results focus on three main areas: observed structural behaviour, changes in students' conceptual understanding, and students' reflections on the value and limitations of the shaking table as a learning tool.

4.1 Observed Structural Behaviour

Students consistently reported that the moment-resisting frame exhibited the greatest displacement and failed first, followed by the braced frame, while the shear walls displayed the greatest resistance and lasted the longest. Many students linked visible movement to structural performance: P1 noted that *“the moment frame structure swayed from the beginning... the swaying got to a point of collapse”*, while P5 described moment frames as *“very susceptible to drift”* and extremely prone to fail early. Braced frames were often described as providing intermediate performance, with diagonal bracing reducing movement but eventually failing at higher vibration levels. Shear walls were consistently identified as the stiffest and strongest systems: P5 noted they *“hardly moved at all”*, and P1 observed, *“remained strong throughout the entire test”*.

4.2 Changes in Conceptual Understanding

Quantitative questionnaire data show a significant improvement in students' self-reported understanding of seismic-resistant design. Prior to the experiment, participants rated their confidence on a five-point Likert scale, with a mean score of 2.52; after the simulation, ratings increased to 3.61, as illustrated in Figure 2.

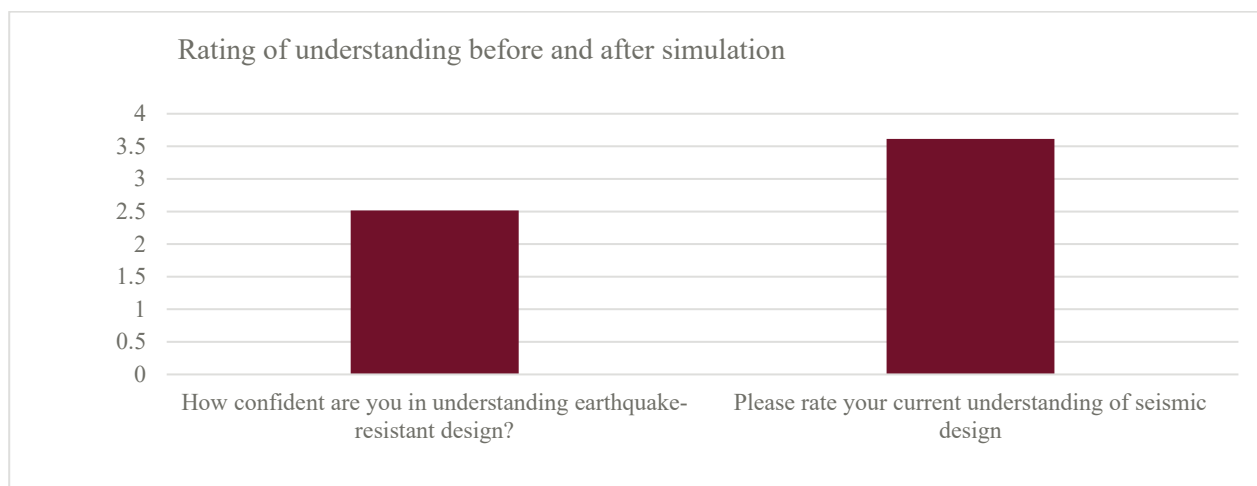


Figure 2: Rating of participants' understanding of seismic resilience

Table 1: Number of participants in each scale

Rating	Number of Ratings Before the Simulation	Number of Ratings After the Simulation
1	4	0
2	14	2
3	6	10
4	7	17
5	0	2

The distribution in Table 1 shows that the majority rated their understanding at level 2, whereas following the experiment, responses shifted mainly to levels 3 and 4, suggesting improved understanding of seismic design. Qualitative responses also support these findings. Some students said the experiment helped them (P13) “*actually remember*” previously taught concepts, while P16 stated that the test “*solidified visually what I have been taught*”.

4.3 Student Confidence and Perceived Learning Value

Students were asked in the post-test survey whether the shaking table provided new knowledge about seismic structural performance. The mean response was high (4.36), as demonstrated in Figure 3, indicating strong agreement that the tool provided new knowledge, beyond prior coursework, while the reported challenge was low (1.29), supporting its suitability for inclusion in architectural courses.

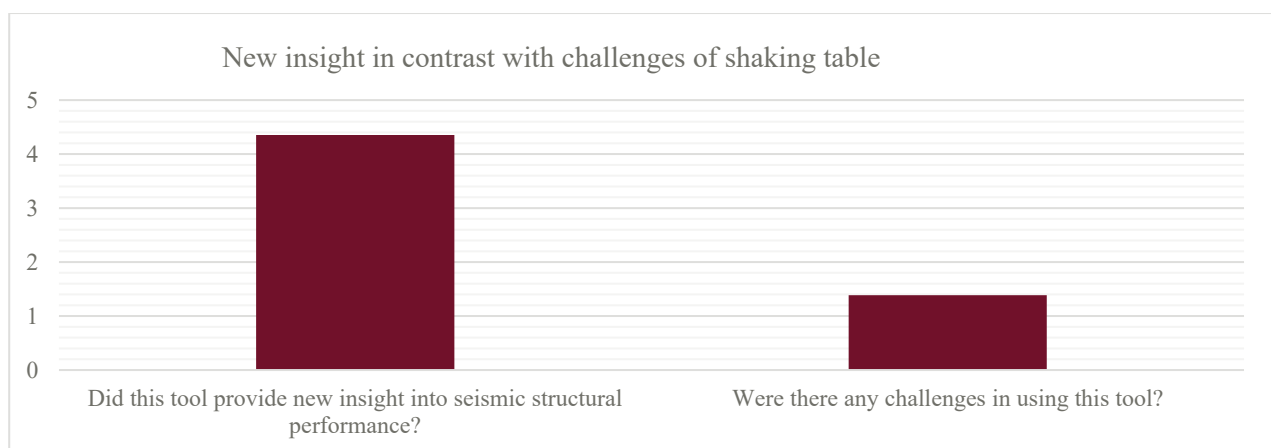


Figure 3: Post-test rating of the shaking table’s challenges and benefits.

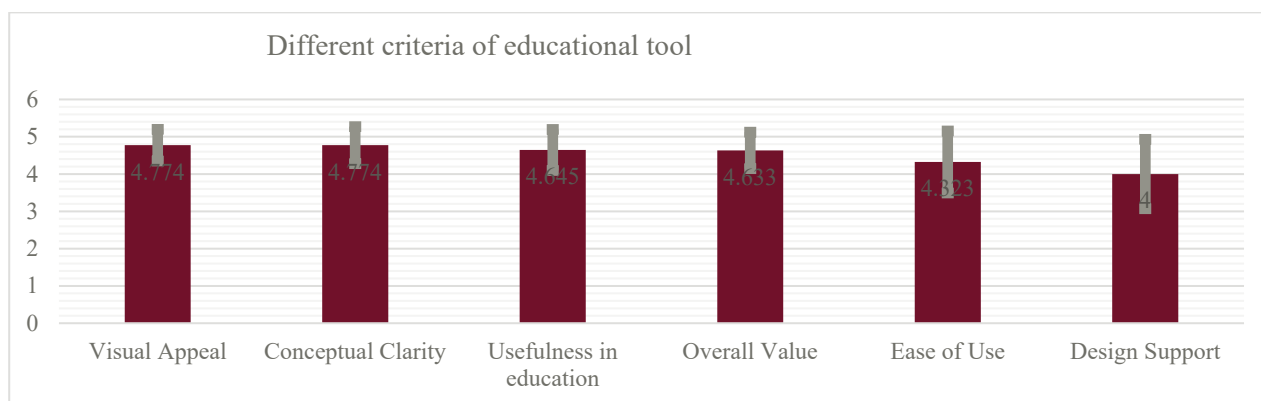


Figure 4: Participants' rating of the efficacy of the shaking table on different criteria

Conceptual clarity and visual appeal scored the highest (4.7 out of 5) with low standard deviations of 0.497 and 0.425 as in Figure 4, indicating strong agreement among participants. Ease of use, overall value and usefulness in education were rated positively. In contrast, design support received a lower score (4.0) and the highest standard deviation (0.93), suggesting greater variation in responses and less confidence in translating these insights directly into design decisions.

4.4 Student-Identified Limitations and Improvement Suggestions

Open-ended responses highlighted areas for improvement. A recurring theme was the need for a clearer link between simulated shaking and an actual earthquake, including magnitude indicators, speed references, or comparisons with real seismic events.

Additional shortcomings were associated with realism, particularly the lack of openings in shear wall models and the use of springs to model moment frames. P29 noted “...no building is fully concrete with no openings...”, as in Figure 5, and other students questioned how closely the models represented the steel frames. Students further suggested testing other geometries, heights, and failure conditions, and allowing more time for exploratory experimentation.

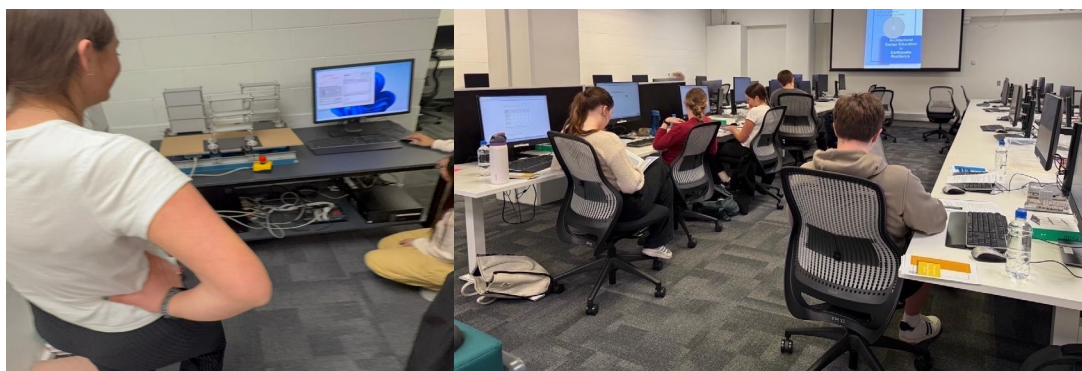


Figure 5: Students taking part in shaking table and reading instruction before building models

5 DISCUSSION: WHAT THE FINDINGS MEAN

This research aimed to determine whether a shaking table, combined with physical models, would help architecture students better understand seismic-resistant design.

5.1 Making Seismic Behaviour Visible and Comparable

One of the major results of the shaking table experiment is the visualisation of structural behaviour. Students consistently identified the same performance sequence: moment frames failed first, then braced frames, and lastly the shear walls. This alignment with structural principles (Sneha et al., 2019) indicates that the experiment supported an understanding of stiffness, lateral resistance, and load distribution.

Compared with lecture-based teaching, where dynamic behaviour is frequently discussed but rarely observed (Morales-Beltran & Yildiz, 2020), the shaking table allowed students to see movement, deformation, and collapse. Several students contrasted their expectations with observations. P1 was surprised that the moment frame *“was the first one to go,”* whereas P14 said that the experiment *“solidified in a visual manner what I have been taught in lectures.”* This supports experiential learning theory, which holds that concrete experience and reflection are more effective than abstract explanation alone (Kolb, 2015). Practical experimentation thus helps bridge this pedagogical gap by converting abstract concepts into observable behaviour.

5.2 Conceptual Understanding and Design Application

The quantitative data show a significant improvement in students' self-reported comprehension, with mean scores increasing from 2.52 to 3.61 (Figure 1). This shift suggests a significant learning impact even within a single experimental session, with the majority reporting understanding above the midpoint of the scale, as shown in Table 1. The findings also reveal that conceptual understanding and visual appeal were rated highly, while design support received a relatively lower score. This suggests that the students understood the structural behaviour but were less confident in applying it to design.

This reflects the concern that structural behaviour does not necessarily translate into design without clear links to architectural constraints (Kam & Pampanin, 2012), such as openings, material choices, and spatial organisation. Some of the participants noted similar issues as P22 questioned how shear walls would behave *“when windows are added,”* while P28 noted that *“no building is fully concrete with no openings.”* These comments suggest that students were beginning to critically evaluate the shortcomings of simplified models, indicating constructive engagement.

5.3 Learning Through Failure and Comparison

The uniqueness of this study lies in its ability to support comparative learning among three different seismic designs. Learning from visible failure was repeatedly highlighted in students' responses. The participants explained how collapse, excessive drift, or joint deformation helped them understand why some systems performed poorly. P9 noted that watching braces go through *“tension and compression”* clarified how forces flow in the structure. This aligns with Karadag & Canakcioglu (2024), who argue that repeated exposure to structural failures is an effective learning tool for architecture students. Nonetheless, some students remained confused about the intensity of shaking and its links to real earthquakes, suggesting that observation alone is insufficient without guidance (Morales-Beltran & Yildiz, 2020).

5.4 Engagement, Confidence, and Educational Value

Students' responses reveal strong engagement with the shaking table. High ratings for visual appeal, usefulness, and overall value indicate the experiment was interesting and user-friendly, whereas the low challenge rating indicates minimal barriers. Some students compared the shaking table to passive learning. P19 found it *“easier to pay attention than a video,”* and P31 noted that *“seeing what actually happens”* was more effective than traditional lectures. These responses challenge the claim that digital simulation alone is sufficient for explaining structural systems to students (Rajaram, 2023). Instead, they support a blended

approach that incorporates physical experimentation, suggesting that shaking tables should complement rather than replace digital tools, thereby fostering experiential understanding.

6 IMPLICATIONS FOR ARCHITECTURAL EDUCATION

The results suggest that shaking table experiments can play an important role in architectural education by strengthening conceptual understanding of seismic behaviour and increasing student confidence. However, their effectiveness depends on thoughtful integration in the curriculum.

Without clear connections to architectural constraints and design processes, these experiments may remain illustrative rather than transformative. The participants' responses indicate a productive direction for future pedagogy, including the integration of openings, a variety of geometries, and connections between physical responses and real-world events. Notably, the results suggest that the shaking table should be used to complement lectures, instructional videos, and computer simulations, rather than replacing them.

7 CONCLUSION

The study explored the use of a shaking table combined with MOLA kits as a pedagogical tool in architectural education. The findings reveal that the shaking table was an effective learning tool, with students reporting increased confidence after the experiment and valuing the ability to visualise and compare seismic structural systems side by side.

Students consistently identified moment-resisting frames as the most fragile and shear wall systems as the toughest. These empirical observations align with well-established structural engineering principles and suggest that physical experimentation helped students relate theoretical concepts to observable phenomena. Quantitative data further indicate an overall improvement in post-test self-reported understanding of seismic design, supported by qualitative responses highlighting increased clarity and engagement.

However, limitations of the shaking table and MOLA kits combination emerged when used in isolation. While the respondents rated the instrument highly for conceptual clarity and visual instructiveness, its usefulness in design application received a relatively low rating. Participants raised concerns about realism, particularly the absence of openings, indicating awareness of the gap between experimental models and real buildings.

These observations suggest that shaking table tests could be most effective as part of a broader pedagogical strategy alongside other tools. They support early-stage understanding of seismic behaviour by enabling observation, comparative analysis, and reflective critique, but require integration with design-focused instruction to guide architectural decision-making.

The current study is limited to a single cohort at a single university and relies on self-reported understandings. Future research should examine the long-term effects on design practice and compare different outcomes across different institutions. Also, future research should explore how knowledge gained from shaking tables can be transferred into design decisions.

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