Article

New Image Recognition Technique for Intuitive Understanding in Class of the Dynamic Response of High-Rise Buildings

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Abstract: In the last years, more and more studies highlight the advantages of complementing traditional master classes with additional activities that improve students´ learning experience. This combination of teaching techniques is specially advised in the field of structural engineering, where intuition of the structural response it is of vital importance to understand the studied concepts. This paper deals with the introduction of a new (and more encouraging) educational tool to introduce intuitively students in the dynamic response of structures excited with an educational shaking table. Most of the educational structural health monitoring systems use sensors to determine the dynamic response of the structure. The proposed tool is based on a radically different approach, as it is based on low-cost image-recognition techniques. In fact, it only requires the use an amateur camera, a black background and a computer. In this study, the effects of both the camera location and the image quality are also evaluated. Finally, to validate the applicability of the proposed methodology, the dynamic response of small-scale buildings with different typologies is analyzed. In addition, a series of surveys were conducted in order to evaluate the activity based on student´s satisfaction and the actual acquisition and strengthening of knowledge.

Keywords: Intuitive learning; Dynamic response; Small-scale model; Image-recognition; Shaking table

1. Introduction

Mathematical models are used to simulate the response of the structures under static or dynamics loads. In structural courses, these models are taught based on a theoretical approach mainly focused on mathematical equations (Fogarty *et al*. 2018). For example, students are traditionally introduced into the static structural response of structures by the stiffness matrix method (Lozano-Galant *et al*. 2013). This procedure uses the members' stiffness relations for computing internal forces and nodal displacements by equilibrium and stiffness equations. On the other hand, for a dynamic simulation, students are usually introduced into modal analysis procedure (Peng *et al*. 2019). In this matrix method, the equations are as a dynamic spring mass system, where eigenvalue analysis provides information of both the frequencies and mode shapes of the structure. These static and dynamic approaches are always based on simplifications. For example, the stiffness matrix method assumes the elements with idealized mechanical and material properties interconnected at the nodes, uniform mechanical and geometrical properties and ideal boundary conditions, among other simplifications. Unfortunately, because of these simplifications actual structures on site rarely correspond to the numerical models. In this case, to get a representative behavior of the structure, the calibration of the model parameters on site might be advised (Lei *et al*. 2019). This calibration can use Structural System Identification (SSI) techniques to measure the actual response of the structure onsite by health monitoring systems (such as accelerometers, glass fiber wires or strain gauges). The problems with these systems to both their installation and maintenance on site. In the last years image-recognition techniques have emerged as an economic alternative to the sensors, as they have significant advantages, such as: flexibility to extract displacements of any points on the structure from a single video record, capacity to monitor with a reduced cost in real time, easiness to measure the structure without the need of installing additional elements. In the structural engineering field, image-recognition techniques have a very wide scope of applications, from material mechanical characterization to structural analysis. In fact, many examples of applications of this method can be found in the literature to monitor the dynamic behavior of bridges (see e.g. Ye *et al*. 2015) and (Ye and Su 2018)), and buildings (Jaynes *et al*. 2003) and (Sahar *et al*. 2010). But not only for structural analysis but also in other fields as for example traffic engineering analysis using plate scanning data (see for example Sanchez-Cambronero *et al*. 2017).

Despite the many works published about this topic, many researchers agree that this procedure is still under development and it is expected a huge technological progress in the coming years. In fact, according to (Candelas *et al*. 2015; Ali *et al*. 2016) most applications of the image-recognition techniques in the literature are focused on measurements of small-scale laboratory structures. The application on large structures on site is traditionally based on the analysis of a limited number of points for a short time period. In the near future, it is expected that the development of image-recognition techniques will enable a more efficient application of this methods on real structures (Feng and Feng 2018).

Although the importance of Structural Health monitoring techniques, most universities only address this topic on advanced courses based (almost exclusively) on theoretical classes. There is no doubt that this mathematical approach is a compulsory requirement to achieve a deep understanding of the actual response of the structural systems on site. Nevertheless, many experiences have proved the benefits of adding complementary methodologies to strength the students' intuitive perception of this kind of problems. In fact, the traditional teaching procedure has been complemented with new and innovative approach, such as the project-based learning (Romero and Museros 2002; Katsanos *et al*. 2011; Ionescu *et al*. 2013; Basso and Innocenti 2015; Chacón *et al*. 2017, and Sanchez-Cambronero *et al*. 2021).

The analysis of the literature shows the interest to develop more innovative and efficient teaching methodologies that ease students to understand structural concepts (such as dynamic behavior of structures) that are hardly perceived from just the mathematical formulations (Gross and Musselman 2018). For example, many authors (such as Chacon and Oller 2017; Mahajan and Sonparote 2018; Slocum *et al*. 2018, and Li *et al*. 2018) have proposed practical activities to monitor the dynamic response of small-scale models on educational shaking tables from low-cost sensors. In fact, experiences learned in this work has proven the learning benefits of including small-scale model analysis when teaching the dynamic response of structures.

This paper aims to improve students' learning experience of complex concepts (such as dynamic response of structures) by combining the traditional theoretical classes with more intuitive activities that enable to develop students' intuitiveness. To do so, in this paper a new educational tool is proposed to monitor the dynamic response of small-scale structures from image-recognition techniques. The analyzed models are built with an economic and easy-to-build construction set name K'nex and they are tested on the educational shaking table of the Civil Engineering school of University of Castilla-La Mancha (UCLM) in Spain. The objectives of the proposed methodology are double. On the one hand it provides students with an intuitive and efficient learning tool to improve their learning experience. On the other hand, the proposed tool illustrates how innovation can be used to solve efficiently problems as complex as the structural health monitoring of structures with low-cost solutions, encouraging students to keep their mind open for innovative solutions for their future engineering problems.

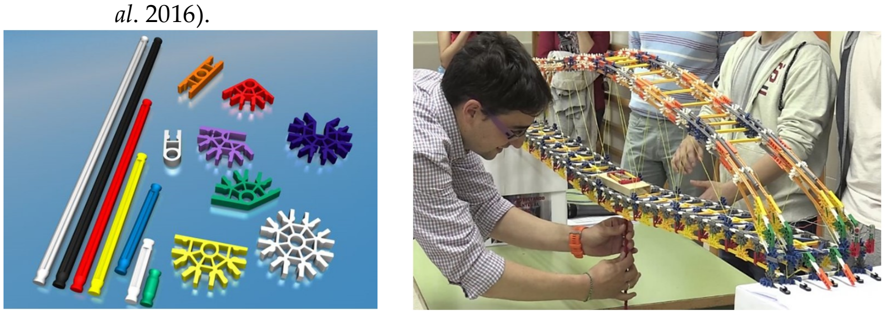
The paper is organized as follows: In Section 2, the modeling of the dynamic response of small-scale buildings in the low-cost shaking table of the UCLM is presented. In Section 3, an algorithm to monitor the dynamic response of buildings by image-recognition techniques is proposed and described in detail. In Section 4, the developed algorithm is applied to an academic example. In addition, different parametric analysis (such as image quality and location of the camera) are carried out to illustrate the influence of these parameters on the accuracy of the estimated response. In Section 5, the application of the proposed tool in a class activity is presented. In this activity, the dynamic response on an educational shaking table of small-scale building with different structural typologies is evaluated. Finally, in Section 6 some conclusions are drawn.

2. Simulation of the Dynamic Behavior of Scale Buildings

In this section, the application of the construction set K'nex for the construction of small-scale structural models is first reviewed. Then, the main properties of the educational shaking tables used in the literature to teach dynamic concepts are reviewed. Finally, the characteristics of shaking table used in this work (shaking table of the Civil Engineering School of the UCLM) is described in detail.

2.1. Structures Made of K'nex

K'nex (K'nex 2019) is a construction set made of plastic bars and connectors as shown in Fig. 1.a. This set has been extensively used for the education of civil engineering concepts, strengthening students' curiosity, imagination and intuitiveness. Examples of the application of this material with educational purposes refer to student competitions (see Fig. 1.b) in bridges (UCLM 2019, Lozano-Galant *et al*. 2018) and building construction (Lloyd 2011). Other authors have used this material to measure natural frequencies, demonstrate the effect of the rigid/flexible diaphragms in buildings, testing the mode shapes of multi-story buildings or analyze the damper effectiveness of structures (Estes *et al*. 2016).



a) b)

Figure 1. Pieces of k'nex (a) and construction of a bridge with k'nex (b).

This extensive use of the K'nex construction set can be explained by the easy connectivity of its elements. Unfortunately, this connection system has the inconvenience of generating flexible connections as some rotation between the bars and the connection is always obtained. Different (Bennewitz *et al*. 2012) were presented in the literature to address the stiffness of these connections by laboratory tests. The strength of the K'nex bars has also been characterized by other scholars (Estes 2014).

The K'nex bars are divided according to their length depicted with a different color: green, white, blue, yellow, red, and grey. The structural characteristics of the K'nex bars (color, length, and inertias) are summarized in Table 1 (Estes 2014). In this table, the terms Ix, Iy and Iz refer to the moments of inertia about the axes X, Y and Z specified in the sketch. All bars have the same cross-sectional area with a value 0.2513 cm^2.

Table 1. Mechanical properties of different K'nex bars (Estes, 2014).

Color	Length (cm)	Ix (cm^4)	Iy= Iz (cm^4)
Grey	19.1	0.008	0.005
Yellow	8.5	0.008	0.005
Blue	5.5	0.008	0.005

Fig. 2 presents a picture of an academic example of a small-scale building build with K'nex elements. This structure represents a 3D frame building with four columns and one-story high. This figure also includes the axes (x, y and z) used in the model.

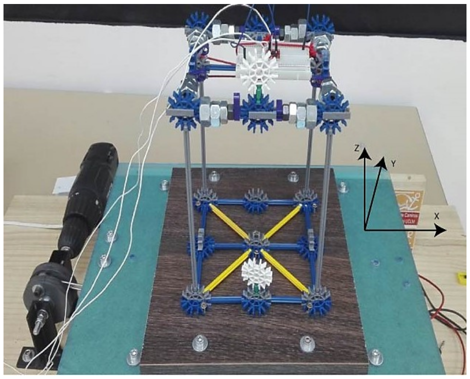


Figure 2. Analyzed small-scaled building using the K'nex elements and nuts.

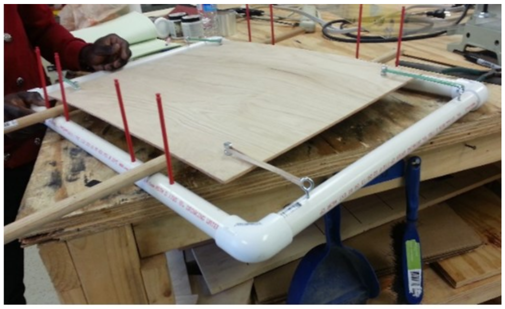
One problem of the building models developed with K'nex refers to the reduced mass of this material elements. For that reason, to simulate the dynamic response of the structure, the use of additional elements that provide mass to the model is advised. These elements were chosen as a group of nuts disposed along the bars located at the top story of the building. These characteristics of the used nuts are presented in Table 2. This table the diameter and the unitary weight of each of the 4 types of nuts used in simulated structure (M9, M10, M13 and M15) are shown. The introduction of these elements into the small-scale models is illustrated in Fig. 2. As shown in this figure, 32 nuts (8 units of each type) are symmetrically installed at the four sides of the top story of the model. The total weight of all the used nuts is 408 gr.

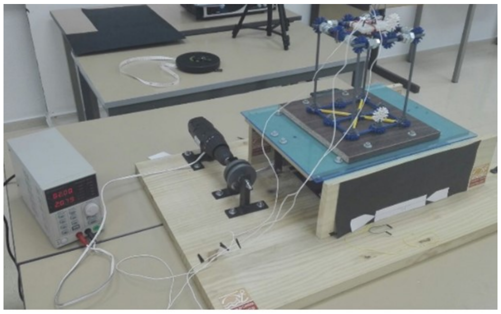
Table 2. Properties for the nuts used to introduce mass into the small-scale model with K'nex.

Nut type	Diameter (cm)	Unitary Weight (g)
M9	0.9	4.66
M10	1.0	10.0
M13	1.3	14.9

2.2. *Shaking table*

A shaking table is a device used for the dynamic excitation of structural models. These kind of tables can be used in real scale models. For instance, the shaking table of University of California in San Diego (UCSD 2019), enables the analysis up to 5 stories buildings. These tools are also traditionally used for the analysis of small-scale structures for educational purposes. In most cases, the excitation used in the educational shaking tables changes from manual control to the electrical/automatic one as shown in the Figure 3.a and 3.b respectively.





a) b)

Figure 3. Shaking table. (a) Manual excitation and (b) electrical excitation at University of Castilla-La Mancha.

Various types of shaking tables have been developed by scholars in terms of the load in one or two directions (Cimellaro and Domaneschi 2018). For instance (Righettini et al. 2018) developed an emperical nonlinear model for a servo-hydrolic uni-axial shaking table capable of simulating acceleration, velocity and position outputs of the system with respect to various types of inputs like pulse and sinusoidal signals for a different range of frequencies and specimens. Scaled shaking tables have been used in China for investigating the characteristic of the granular landslide deposit affected by vertical and horizental seismic waves (Chen 2019). The shaking table of Sharif University in Theran-Iran has been used to simulate earthquakes including lanslide displacement on the slopes (Jafarzadeh et al. 2019).

The construction cost of shaking tables plays an important role when the device is built for educational purposes as in this case very limited funding options are traditionally available. For this reason, to illustrate the structural mechanism to students, low-cost solutions are conventionally developed. This is the case of the present work as a low-cost shaking table was used. This table is presented in Figure 3.b and it was developed by the CEU San Pablo university for the Civil Engineering School at University of Castilla-La Mancha (UCLM) in Spain for educational purposes. The excitation mechanism of this table is based on a drill, PSB 650 RE Bosh model, that produces a sinusoidal excitation, which frequency is controlled with a Programmable DC Lab Power Supply (LABPS3005DN model).

In the last years, development of low-cost sensors controlled by open source microcontrollers (El-abd 2017) have propagated an authentic educational revolution. In fact, the use of these techniques are introduced more and more frequently in high School and university courses (Berry 2016). For example, many scholars have monitored the dynamic response of small-scale structures with this system (see e.g. Zhang *et al*. Damc and Sekerci (2019) established a low-cost Arduino-based single-axis shaking table with maximum frequency of 17 Hz and speed as high as 350 mm/s. Sanghavi, Patil and Shah (2012) also proposed educational shaking tables monitored low-cost LVDT sensors for the College of Engineering in India. In the following section, a new tool based on image-recognition techniques is proposed to monitor the dynamic response of small-scale structures on educational shaking tables.

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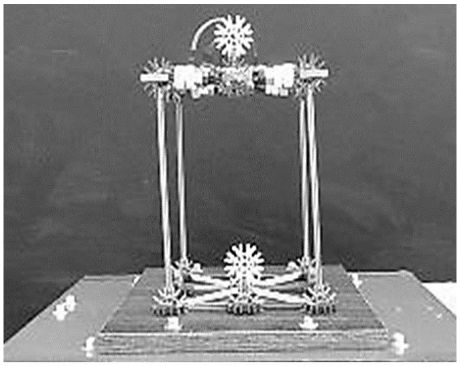
3. Characterization Dynamic Behavior of Structures With Image-recognition Techniques.

In this section, a low-cost procedure is proposed for the characterization of the dynamic behavior of small-scale structures. The proposed tool is used to improve the teaching experience in the subject "Building Design" of the Master in Civil Engineering at UCLM. This subject has a duration of 45 hours and it introduces students into the static and dynamic design of buildings from a mathematical approach. Traditional master classes are complemented with additional activities aiming to improve the students' learning experience. The subject duration is 45 hours.

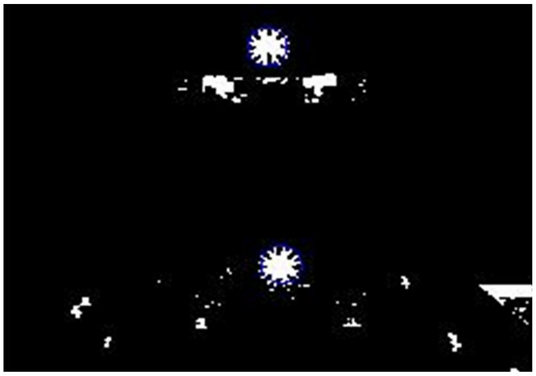
The idea of the proposed tool was initiated from the concern of the professors to provide a new educational tool to develop the students' intuition on structural response of structures under dynamic loads. This tool is based on an image-recognition algorithm developed by the authors in MatLab (Matworks, 2019). Obviously, the application of the proposed tool is not limited to small-scale buildings as it can be easily adapted for educational purposes to the study of many other engineering fields (such as transportation, mechanical engineering, industrial engineering, or robotics, among many others).

3.1. Algorithm for the dynamic analysis from image recognition techniques

The developed algorithm applies image-recognition techniques to the different frames of the small-scale structure movement that has been recorded by a camera (Fig. 4.a). In each of these frames, the location of a set of visual targets (Fig.4.b) is identified by the analysis of the image pixels. To ease the identification of these target points a black background is placed behind the structure. A graphical scale is also placed at the base of the shaking table to transform pixels into centimeters in order to identify the magnitude of the movements. Once the positions of the target points have been determined, the time spacing among frames can be used to define both the speed and the acceleration of the different stories over time.



a)



b)

Figure 4. Developed image-recognition tool: Recording process of the movement carried out by a camera (a), and the target points after image processing at each story (b).

The proposed algorithm for the dynamic analysis is as follows:

- **Input**: A video of at least 10 seconds where the camera has been recorded the movement of the building.
- **Outputs**: The time-dependent position, speed and acceleration of each target point (i.e. of each story building) obtained of the analysis of each frame of the recorded video
- **Step 0**: Reading the video and setting the reference values: The recorded video must be read in order to get the frames per seconds (fps) that implies the time increment (Δt) that will be used to derive speeds and acceleration of each story. For a better

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application of the image-recognition techniques, the RGB video must be converted to grayscale eliminating the hue and saturation information while retaining the luminance. It is also necessary to set the number of seconds (n_sec) to analyze the building movement and the length (L) of the graphical scale so the transformation from pixels to centimeters can be carried out.

- **Step 1**: Building characterization: Using the first frame of the video, some information of the building is collected to better perform each image analysis. In particular:
- **Step 1.1**. Determining the color of the target spot. To obtain a good threshold value for Step 2, pick some samples of color (5-10) of one of the target spots located at the stories. This sample is stored in ref_color.
- **Step 1.2.** Determining the radius of the target spot. Using the frame, measure (in pixels) the radius (rt) of the target spot.
- **Step 1.3.** Determining the number and height of each building story. Using the frame, determine a preliminary (z_s^0) position the height (h_s) of each story (s) from a total of ns.
- **Step 1.4.** Determining scale factor. Using the frame, determine the length (L_p) in pixels of the graphical scale and obtain the scale factor to transform pixels into centimeters as sf=L/L_p . Set the number of analyzed frames equals to 1 i.e. f=1. and go to Step 2.
- **Step 2**: Image thresholding: Using the histogram of frame f and ref_color, thresholding the image so that the colors in ref_color go to white color and the rest go to black color. Compute and fill connected components in order to better identify the target spots with white color. Go to Step 3.
- **Step 3**: Image binarizing Binarize the image obtained in Step 2 so that pixels with white color take value of 1 and 0 otherwise. Set s=1 and go to Step 4.
- **Step 4**: Calculating the position of each target point: We assume that the position of the target point of the story s is the center point (x_s,z_s), of the circle of radius rt (defined in Step 1.2) which maximizes the number of ones inside of it. For that, the algorithm moves a dummy circle looking for this maximum in a searching band defined as showed in Figure 5. Since the obtained center point has its coordinates in pixels, the scale factor sf must be used to transform pixels into centimeters and stored them in the results matrix. If s<ns, do s=s+1 and repeat Step 4. If s=ns another frame must be analyzed if possible. Then if f<n_sec xfps , do f=f+1 and go to Step 2. Otherwise go to Step 5.
- **Step 5**: Getting the results: Once all the desired frames were analyzed the results matrix is used to derive the movement of the building target points, their maximum displacements, their velocities and their accelerations.

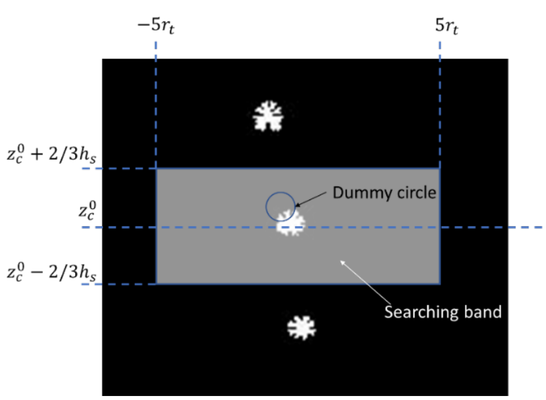

Figure 5. Definition of the searching band to obtain the position of a target point.

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In the following sections, two examples of growing complexity are presented to illustrate the applicability of this algorithm.

4. Validation of the developed algorithm

In this section, the developed image-recognition algorithm is applied to a scale building built with K'nex and tested in the shaking table presented in Section 2. To evaluate the accuracy of the estimations for different resolutions and camera locations, a set of parametric analyses are also carried out. Finally, to validate the proposed methodology, the results of the proposed algorithm are compared with those obtained with a low-cost accelerometer.

4.1. Application of the image-recognition algorithm

In this section, the proposed image-recognition algorithm is applied to the 1 story building presented in Figure 6. A target point (white connector at mid span) is included at each story level to monitor the dynamic response in the shaking table excitation axis. Low-cost camera (model Nikon Coolpix A100 with a cost of approximately 60€) with a maximum resolution of 20.1 Megapixels and 25 frames per second was used to record the building movements on the shaking table. From these recorded information displacements, velocities and accelerations were obtained by the algorithm presented in Section 3. In the recording process, the camera resolution was fixed to 20.1 Megapixels and it was located at a distance of 50 cm from the model. The obtained deflections at the two target points (top and base levels) by the image-recognition algorithm are presented in Figure 6.

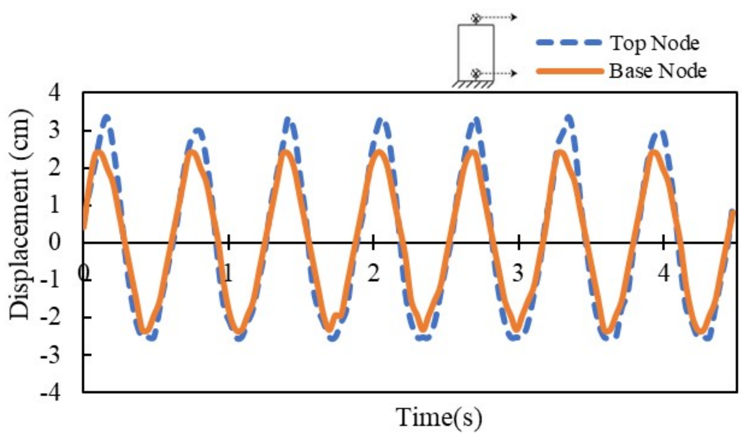

Figure 6. Evolution of horizontal displacements at the top and base levels with a 20.1 Megapixels resolution camera located 50 cm from the model.

The analysis of Figure 6 shows how the proposed algorithm identifies adequately the sinusoidal movements of the shaking table. In addition, as expected, this figure shows that the movement of both nodes are properly synchronized as well as that the top node presents higher movement amplitudes. Figure 6 also illustrates an asymmetric response of the structure as the maximum positive and negative values of the top node were different. In fact, the maximum positive displacements (3.35 cm for the top node and 2.366 for the base node) are higher than the negative ones (-2.504 cm for the top node and -2.317 cm for the base node). These differences might be explained by the wrong calibration of the shaking tables as the movement in one direction is higher than in the other. Nevertheless, this lacks calibration does not jeopardize the applicability of the proposed methodology for educational purposes.

The velocities obtained at the two target points by the image-recognition technique from the analysis of the deflections are presented in Figure 7.

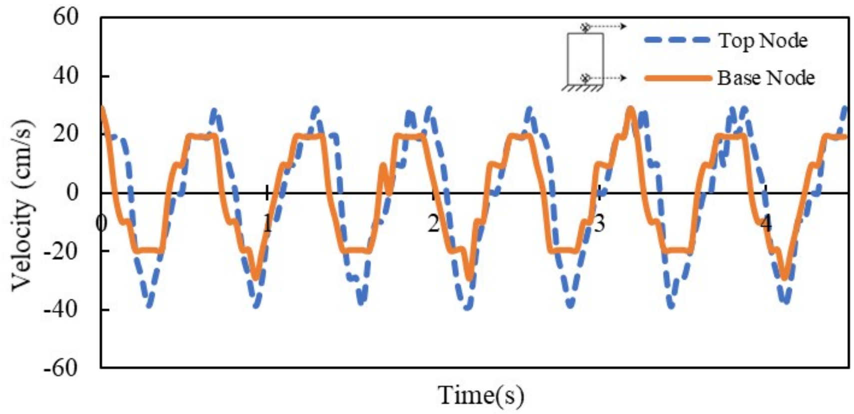

Figure 7. Evolution of horizontal velocity at the top and base levels with a 20.1 Megapixels resolution camera located 50 cm from the model.

The analysis of Figure 7 shows a good agreement between the velocities of both nodes. Obviously, higher velocities are obtained at the top node at that story is also affected by the structure flexibility. In addition, null velocities are measured in both nodes when the amplitudes of their deflections are maximal. A slight offset of the measurement sets is obtained from the numerical integration. As in the case of the deflections, the lack of calibration of the shaking table produces differences between the maximum and the minimum measured velocities. In fact, the maximum positive velocity measured at the top node was -40.5 cm/s, while the minimum one was 30.1 cm/s.

The accelerations obtained at the two target points by the image-recognition technique from the analysis of the velocities are presented in Figure 8.

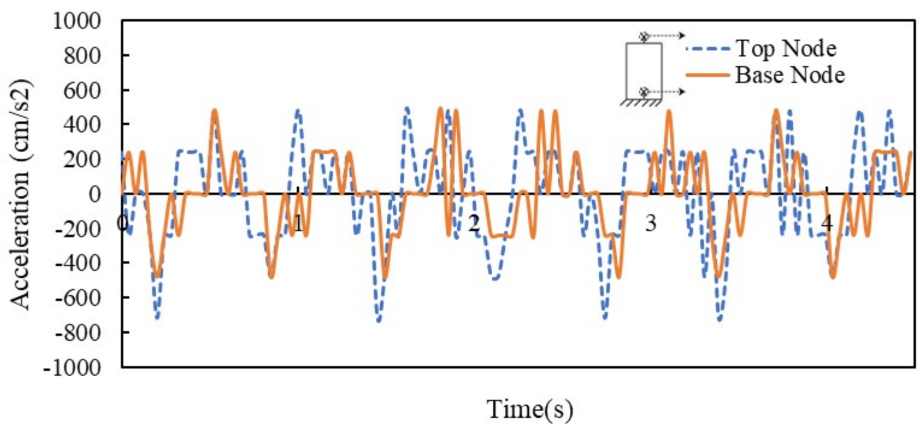

Figure 8. Evolution of horizontal acceleration at the top and base levels with a 20.1 Megapixels resolution camera located 50 cm from the model.

The analysis of Figure 8 shows that the maximum accelerations at the top of the structure corresponds with the points with the higher displacement and null velocity. Nevertheless, unlike the deflections and the velocities, the accelerations are not properly obtained by the algorithm throughout the time due errors in the numerical integration of the velocities. In fact, this figure shows asymmetrical response of the nodes in the structure. The higher values of the accelerations are measured at the top node and exceed the -700cm/s^2 and the 500 cm/s^2.

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In the following section, two parametric analysis are carried out to evaluate the influence in the results of the image-recognition method of the camera resolution and its distance to the shaking table.

4.2. Parametric Analysis of the Camera Location

In this parametric analysis the effect of the camera location is studied. To do so, structural response obtained by 4 different camera locations (50cm, 100 cm, 150 cm and 200cm) are compared. The camera resolution in all these analyses is fixed as 20.1 Megapixels and 25 frames per second. The obtained deflections, velocities and accelerations at the top node are summarized in Figures 9, 10 and 11 respectively.

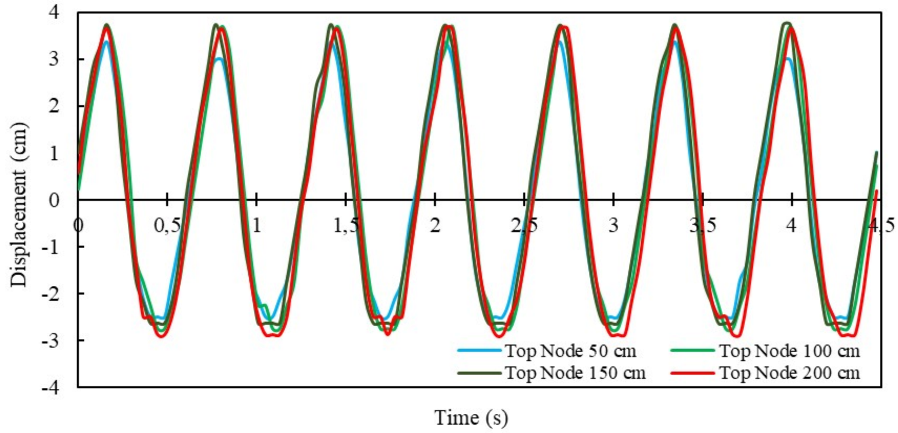

Figure 9. Displacements measured by the image-recognition tool for four distances of the camera (50, 100, 150 and 200 cm).

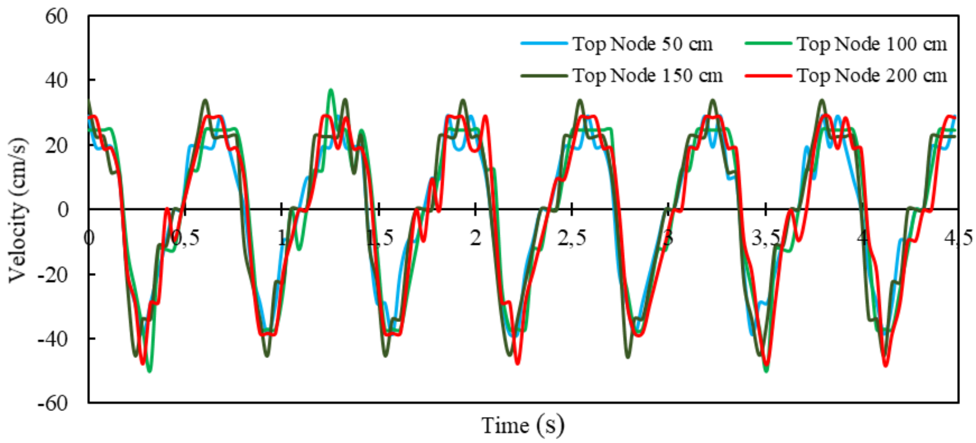

Figure 10. Velocity measured by the image-recognition tool for four distances of the camera (50, 100, 150 and 200 cm).

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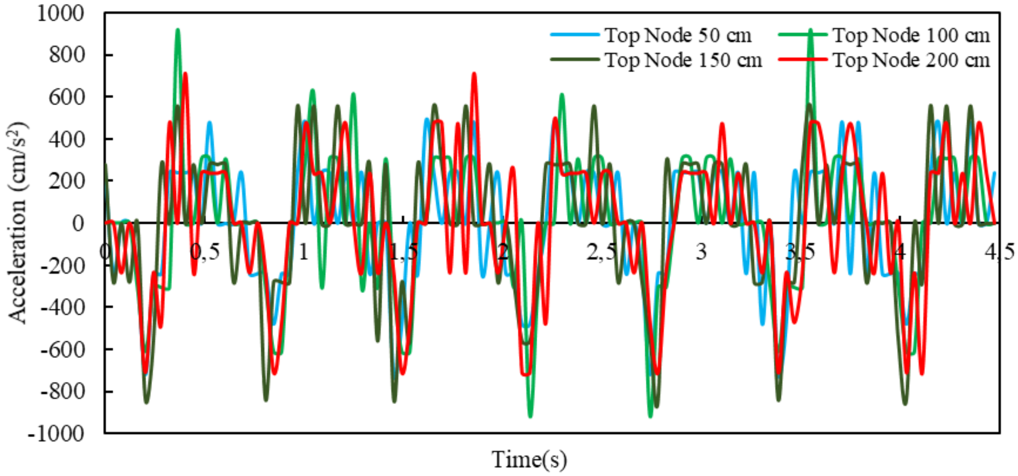

Figure 11. Acceleration measured by the image-recognition tool for four distances of the camera (50, 100, 150 and 200 cm).

The analysis of Figure 9 shows slight differences between the maximum and minimum deflections obtained by the developed tool for different camera distances. In fact, the higher the distance of the camera from the shaking table, the higher the amplitude of the movement obtained by the algorithm. For example, the maximum negative amplitude changes from -2.725 cm to -3.013 cm when the camera distance is increased from 50 cm to 200 cm. An intrinsic characteristic that it is not affected by the camera distance is the movement period, as for all four analyzed cases it remains constant with a value of 0.645. s.

The analysis of Figure 10 shows a good agreement of the overall response is obtained by the four analyzed distances. Nevertheless, as in the case of the deflections, slight differences of the maximum values appear. In this case higher velocities are usually obtained for the higher distances between the camera and the shaking table. The maximum velocity (-49.3cm/s is obtained at the 200 cm distance).

Figure 11 shows an overall agreement of the accelerations at the top node measured by the developed algorithm for the four analyzed distances. The higher acceleration values are obtained for the 100cm distance.

4.3. Parametric analysis of the camera resolution

In this parametric analysis the effects of the camera resolution are studied. To do so, structural response obtained by 2 different resolutions with the same low-cost camera (VGA: 640 x 480 pixels and 0.3 Megapixels and High Quality, HQ: 5000 x 4000 pixels and 20.1 Megapixels) are compared. The camera location in these analyses is fixed to 50 cm. The obtained deflections, velocities and accelerations at the top node are summarized in Figures 12, 13 and 14 respectively.

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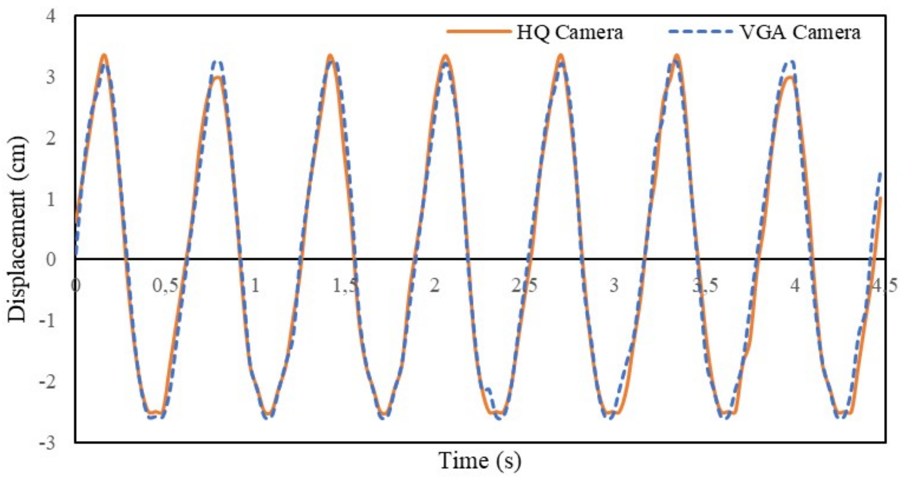

Figure 12. Displacements measured by the image-recognition tool for two camera resolutions (HQ and VGA).

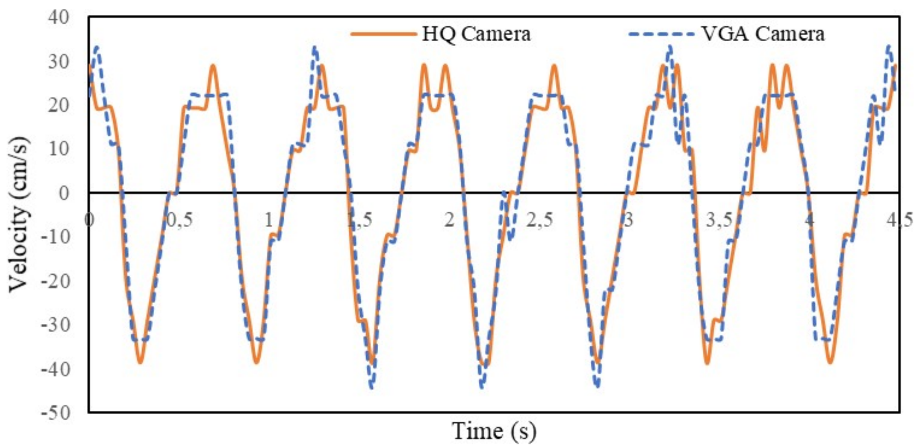

Figure 13. Velocity measured by the image-recognition tool for two camera resolutions (HQ and VGA).

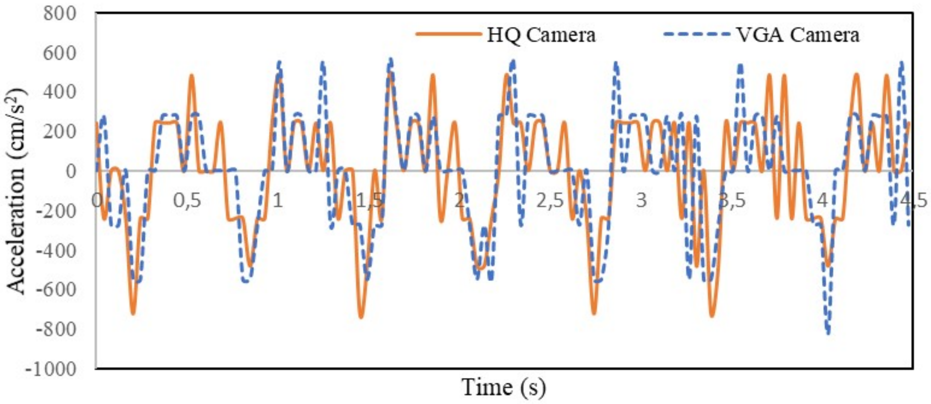

Figure 14. Accelerations measured by the image-recognition tool for two camera resolutions (HQ and VGA).

The analysis of Figure 12 shows negligible differences in terms of the deflections obtained by the developed tool for different camera resolutions. In fact, the maximum and minimum values obtained for both resolutions are practically the same.

The analysis of Figure 13 shows a good agreement of the overall response is obtained by the two analyzed resolutions. Nevertheless, slight differences of the maximum values and minimum value appear. As in the case of the distance analysis, higher velocities are usually when for lower camera precisions. In fact, the maximum velocity (-44.6 cm/s) obtained for the VGA precision is higher than the one obtained for the HQ precision (-39.5 cm/s).

Figure 14 shows an overall agreement of the accelerations at the top node measured by the developed algorithm for the two camera resolutions. The higher acceleration values are obtained for the 100cm distance.

5. Application of the proposed tool for the dynamic analysis of high-rise building in a workshop

To illustrate in class the response of high-rise buildings to seismic loads, a workshop was introduced into the "Building Design" subject. Students were invited to participate on the workshop celebrated on November 2020th. In the workshop, the proposed image-recognition algorithm was applied for the dynamic analysis of a high-rise building. The analyzed structure corresponds with the six-story building presented in Figure 15.a. This figure shows how a target point (white connector) is introduced at each story level. An image of the video introduced into the algorithm is presented in Figure 15.b. This video was recorded with a camera resolution of 20.1 Megapixel located 50cm from the structure. The location of the target points obtained by the image-recognition algorithm are presented in Figure 15.c. The analysis of this information can be used to define the lumped mass model of the building.

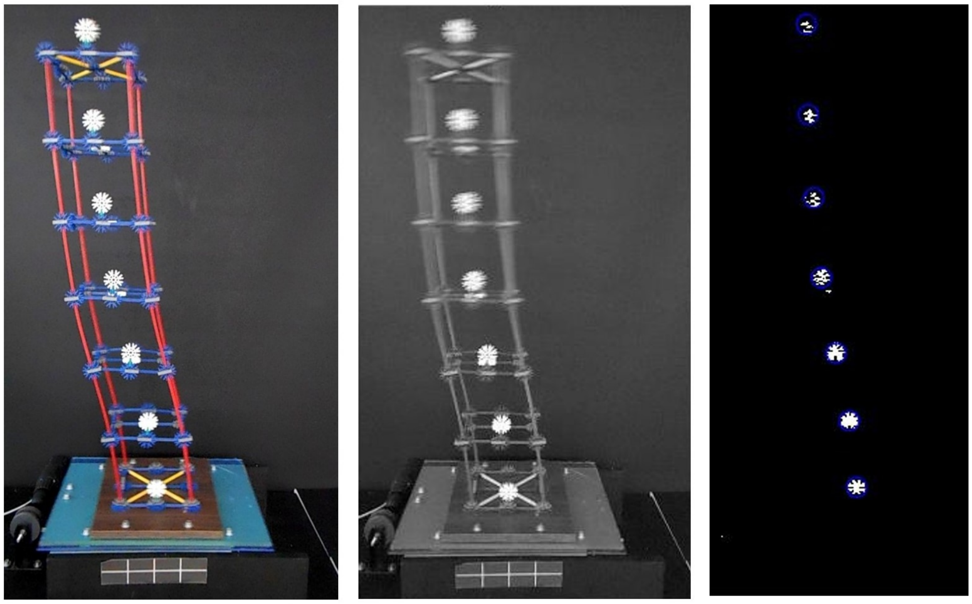

Figure 15. Analyzed reference building: (a) Recorded movement on the shaking table, (b) Image after color treatment in the developed algorithm, and (c) position of the target points.

In this activity groups of 3 students were challenged to improve the response of the reference structure presented in Figure 16. As stated by a number of scholars (see e.g. Hezazy (2020) hands-on experiences have great benefits for students, such as: strengthen learning, motivate themselves and help develop imagination and creativity. To illustrate the presented solutions five designs were selected: (1) Shear wall in Figure 16.a: This wall is modeled as a x-bracing façade in the direction of the shaking table movement, The stair core was materialized as a rigid truss situated out of building section, (2) Core in the center presented in Figure 16.b: The stare core was situated close to the center or the building section, (3) Core in the outer face as presented in Figure 16.c. (4) Belt truss as presented in Figure 16.d: This truss is materialized as x-bracing placed between the second and the third story. (5) Damper weight at the top story as presented in Figure 16.e: This dumper is materialized as two heavy nuts (50gr each) hanged from the roof. This solution imitates that used in the Taipei 101 building in Taiwan.

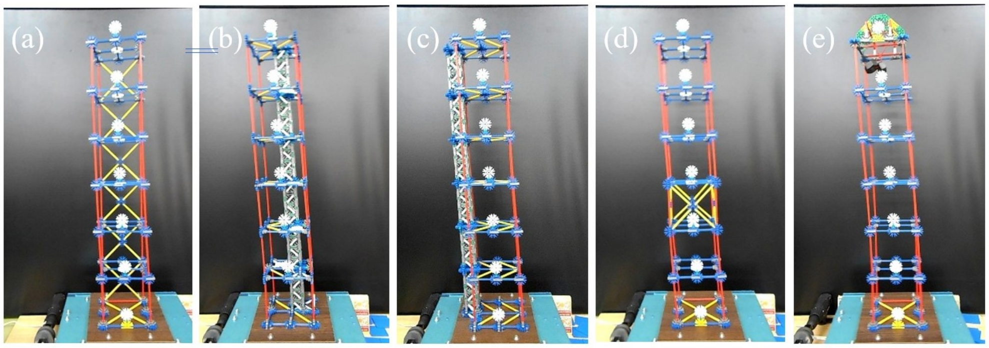

Figure 16. Analyzed building typologies: (a) Shear wall, (b) Centered Core, (c) Eccentric core, (d) Belt truss, and (e) Dumper weight.

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A comparison between the maximum deformations obtained by the five designs proposed by the students and those of the reference model are presented in Figure 17. This table shows that all the all the proposed designs improve the seismic behavior of the reference value. Among these models it is to highlight the effectiveness of the belt truss, the core in the center. the dumper at the top and the shear wall as the maximum obtained deflections were practically zero. On the other hand, the worst response was measured at the asymmetric solution (the core in the outer façade).

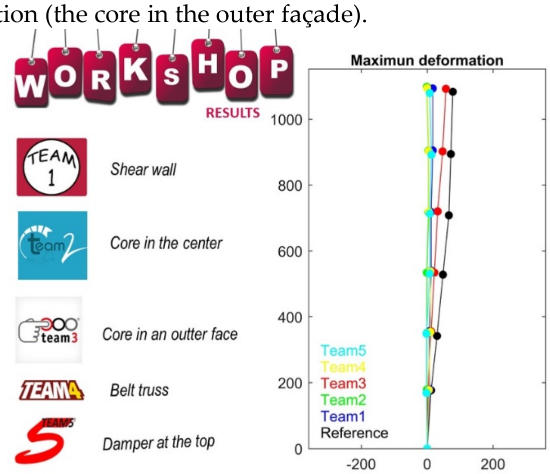

Figure 17. Comparison of the deformations obtained by the different building typolog.

In order to evaluate the learning effectiveness a set of surveys were conducted and evaluated according to the Attention, Relevance, Confidence and Satisfaction (ARCS) model described in the following section.

5.1. Attention, Relevance, Confidence and Satisfaction (ARCS) model

Motivation is a basic parameter to be considered to understand human behaviors, as well as it plays a key role in the teaching-learning process (see e.g. Pintrich 2003, Zhen 2020). The main goal of the workshop is to motivate students with experimentation, while giving them tangible tools to understand advanced structural concepts. In this regard, we applied Attention, Relevance, Confidence, and Satisfaction (ARCS) (Keller 2010) learning motivation model to: (1) validate our methodology, (2) verify the ability of students to improve learning through active teaching, and (3) check that those kind of activities can stimulate learning confidence and, at the same time, effectively improve students' learning satisfaction as well as learning effectiveness.

ARCS model has been applied in a variety of educational settings, in different subject areas and many countries (such as Li *et.al* 2018, and Chang *et.al* 2020).

In the presented workshop, the ARCS model parameters were evaluated through a questionnaire organized as follows:

- **Attention**: 5 questions related to learning interests before the activity
- **Relevance**: 5 technological questions related to the concepts explained during the activity, to check learning effectiveness
- **Confidence**: 5 questions to measure their self-perception of fulfilling a task,
- **Satisfaction**: 5 questions to learn about students' opinions on the suitability of the methodology used.

The survey was organized as a 4-point Likert scale, which is, basically, a forced scale, where the user is forced to form an opinion because there is no 'neutral' option. In addition, some short answer questions were included. All the survey questions are included in Figure 17. As the workshop was held during the Covid-19 global pandemic, some additional sanitary precautions (such as social distance or the use of masks and hydrogels) were adopted. In fact, to evaluate the students' motivation under these cir-

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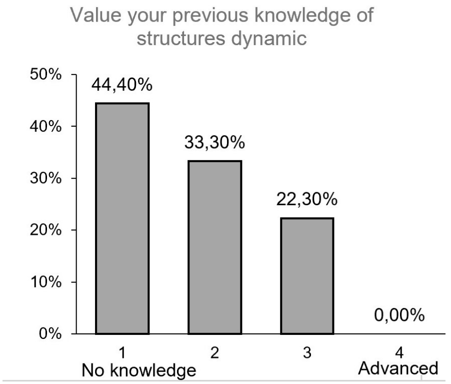
cumstances, a virtual survey was conducted. In this way, students accessed to different google forms via QR codes showed on the screen wall (see Figure 18). The results of the survey are summarized in Figures 19, 20 and 21.

a)  b) 

Figure 18. a) Students using their mobiles to read de QR code. B) Student asking the questions.

a) 

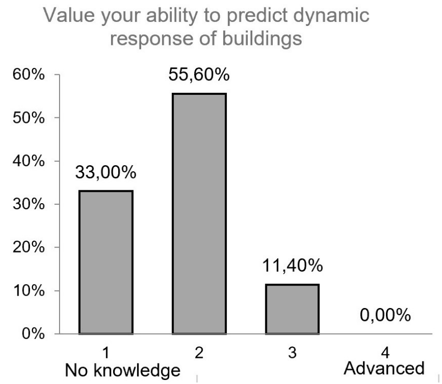
b) 

Figure 19. Survey results: Self-awareness before the workshop: a) Previous knowledge b) Previous ability to predict dynamic response of structures.

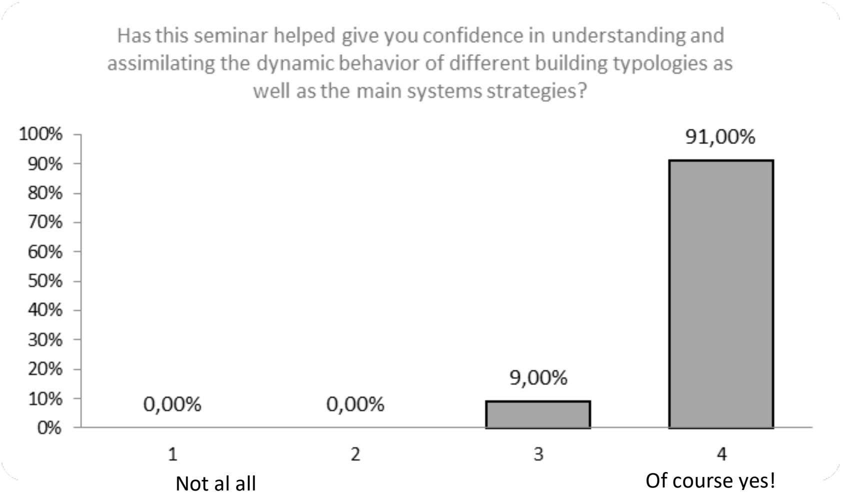


Figure 20. Survey results: Confidence.

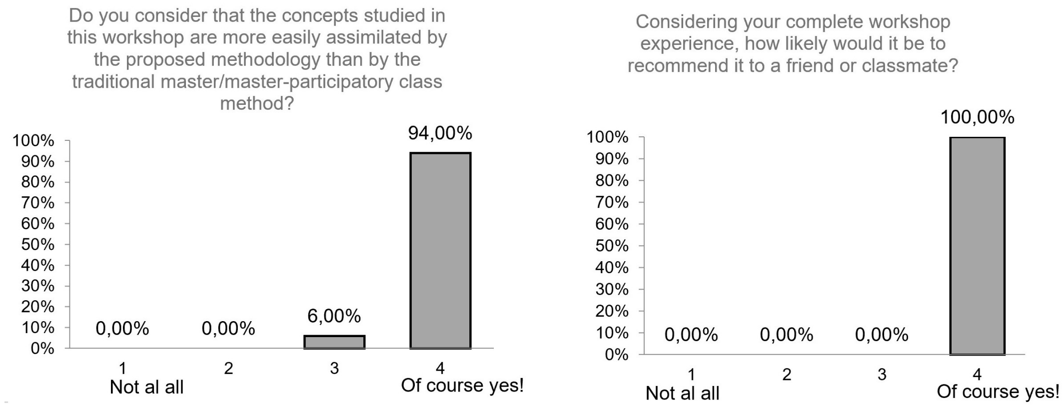


Figure 21. Survey results: Satisfaction.

The analysis of the obtained results showed that students were generally motivated to come to the activity, and their expectations, as they have answered the first question are high and very well directed, such as: "I have come because I think I need to improve my knowledge into issues related to the dynamic behavior of buildings", "To learn the possible response of a structure to seismic loads" or "To learn the mechanisms of resistance to an earthquake".

The previous knowledge of students is analyzed in Figure 19.a and 19.b. On the one hand, the former of these figures shows that before the activity 77.7% of the students scored their previous knowledge as low as 1 or 2. On the other hand, Figure 19.b illustrates that more than 80% of the students expressed their reduced ability to predict the dynamic response of buildings.

Figure 20 presents the students' perception about the utility of the workshop to better understand the dynamic response of buildings. This figure shows that all the students rated as 3-4 their level of understood and assimilation of the concepts.

Figure 21 summarized the satisfaction results. On the one hand, Figure 21.a shows that all students (94% rating 4 and 6% rating 3) considered that the used methodology help to reach a better level of understanding. On the other hand, Figure 21.b shows that all the students would recommend to a classmate the participation of a similar workshop in the future.

The answers to the technical questions (in Figure 22 a bunch of these technical questions are shown) were evaluated before and after the activity to analyze students´ previous knowledge in seismic analysis of structures, as well as to measure and quantify their learning. The results of this analysis showed that the number of right answers before the activity (36%) was significantly increased after the workshop (93%).

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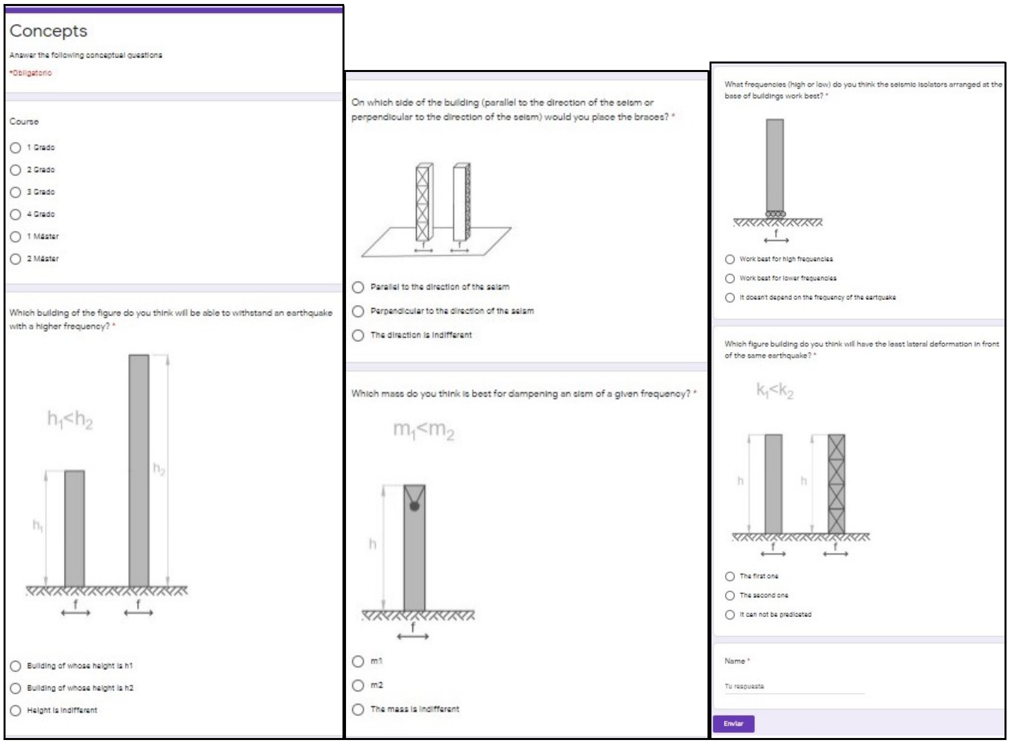

Figure 22. Survey about concepts.

6. Conclusions

This paper proposes to improve the learning experience of the university students by introducing in class activities that strengthen their structural intuition. To do so, an image-recognition tool algorithm is proposed to identify the dynamic response (deflections, velocity and accelerations) of small-scale buildings on an educational shaking table. To evaluate the applicability of this tool, the dynamic response of a simple k'nex building on the educational shaking table of the Civil Engineering School of UCLM was studied. In addition, the effects of both the camera distance to the shaking table and the camera resolution were studied. In both analyzed studies the period of the structure remained constant independently in both studies. Finally, the applicability of the proposed tool in an educational activity in a master level subject is presented. In this activity, students are challenged to improve the seismic behavior of a reference small-scale building. Then, the proposed algorithm was used to compare the different typologies proposed. The survey conducted illustrated the improvement on students' confidence and motivation.

Data Availability Statement: All data, models and codes that support the findings of this study are available from the corresponding author upon reasonable request (Developed algorithm in MatLab and the obtained results from Image recognition technique).

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