Analysis of the Influence of Non-Structural Elements on the Dynamic Characteristics of Buildings

Marcin Błajda[1)], Alicja Kowalska-Koczwara[2*)]

[1)]Cracow University of Technology, Faculty of Civil Engineering, Warszawska 24St., 31-155 Krakow, Poland,
E-mail: marcin.blajda@student.pk.edu.pl
[2*)]Cracow University of Technology, Faculty of Civil Engineering, Warszawska 24St., 31-155 Krakow, Poland,
E-mail: akowalska@pk.edu.pl ; ORCID: 0000-0001-8088-7729

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Abstract

Non-structural elements, although they are usually not treated as primary components of the load-bearing system, may significantly affect the dynamic properties of a building. This applies in particular to partition walls, whose presence, arrangement, and manner of connection to the load-bearing structure may modify the mass distribution and global stiffness of the structure and, consequently, influence the values of natural frequencies and the corresponding mode shapes. Neglecting these elements in computational models may lead to simplifications that reduce the reliability of dynamic analyses. The aim of this study is to assess the influence of selected non-structural elements on the dynamic characteristics of a building. For this purpose, a numerical model was developed using the finite element method in Autodesk Robot Structural Analysis. Two model variants were considered: a model including only the load-bearing structure and an extended model in which selected non-structural elements were included together with their material properties and the assumed interaction with the load-bearing structure. Contact interactions between the non-structural elements and the structural system were also taken into account in the modelling process. For both variants, a modal analysis was carried out to determine the natural frequencies and the corresponding mode shapes. A comparison of the results obtained for the basic and extended models showed that the presence of non-structural elements leads to changes in the dynamic characteristics of the building, including an increase in the global stiffness of the system and modifications of the mode shapes. The magnitude of these changes depends on the type, arrangement, and mass contribution of the considered elements. The obtained results confirm that the inclusion of non-structural elements in computational models allows for a more realistic representation of the dynamic response of a building and increases the reliability of modal analyses used in engineering practice. A possible direction for further research is to extend the analyses to a wider range of non-structural elements, different arrangement variants, and various types of connection with the load-bearing structure. It would also be justified to include contact nonlinearity, validate the numerical models on the basis of in-situ measurements, and analyse the influence of non-structural elements on the building response under actual dynamic excitations, including traffic- and operation-induced vibrations.

Keywords: *non-structural elements, partition walls, dynamic characteristics, modal analysis, finite element method (FEM)*

1. Introduction

The dynamic characteristics of a building, particularly its natural frequencies and corresponding mode shapes, provide essential information about the behavior of the structure under dynamic excitation. Within the framework of linear modal analysis, these characteristics are inherent properties of the adopted structural system and are independent of the external excitation. They are governed primarily by the distribution of mass and stiffness and, consequently, by the mechanical properties of the materials, structural geometry, connections between individual elements, and boundary and support conditions. Reliable determination of modal parameters is therefore an important stage in assessing the response of buildings subjected to seismic, wind, traffic, construction, machinery-induced, or human-induced vibrations.

In conventional structural analysis, elements classified as non-structural are frequently neglected or represented only by their mass. This simplification is based on the assumption that such elements do not contribute to the load-bearing system. In practice, however, internal partition walls and masonry infills remain in contact with adjacent structural components and may participate in the transfer of loads and deformations. Their presence can consequently modify both the mass and stiffness matrices of the numerical model and thus affect its natural frequencies and mode shapes [1–4]. Although the terms partition wall and infill wall are not interchangeable in every structural system, research on masonry infills demonstrates the broader problem of nominally non-load-bearing elements participating in the global dynamic response of a building.

The interaction between masonry walls and the surrounding structure has been investigated using analytical, numerical, and experimental methods. Early studies demonstrated that masonry panels subjected to in-plane deformation may behave similarly to diagonal compression struts, considerably increasing the lateral stiffness of framed structures [5]. This observation formed the basis for numerous macromodeling approaches developed for the representation of masonry infills [6]. Subsequent experimental studies on full-scale and large-scale reinforced concrete structures confirmed that masonry walls may significantly change structural stiffness, vibration periods, deformation patterns, and seismic response [7, 8].

Numerical analyses have similarly shown that neglecting masonry infills may result in an overestimation of the fundamental period and an inaccurate representation of the dynamic behavior of a building [9–11]. The contribution of these elements is not necessarily uniform in all vibration modes. It depends on their material and geometric properties, arrangement, orientation, openings, and degree of contact with the adjacent structure. In addition, vibration-based investigations have demonstrated that modal parameters

may be used to identify the contribution and condition of masonry walls [3, 4]. The influence of the adopted representation of the connections between masonry elements and the structural frame is also important. Different assumptions concerning wall–structure interaction may produce noticeably different numerical values of the dynamic characteristics [2].

The addition of partition walls increases both the total mass and the lateral stiffness of a building. These two effects act in opposite directions: an increase in mass tends to reduce natural frequencies, whereas an increase in stiffness tends to raise them. Previous investigations indicate that, particularly for the lower modes of vibration, the stiffening effect of masonry walls often predominates, resulting in higher natural frequencies than those obtained for the corresponding model without the walls [3, 9, 10]. The scale of this effect is direction-dependent because the increase in stiffness is related to the orientation and spatial distribution of the walls.

Most previous studies have focused on reinforced concrete frames with masonry infills, particularly in the context of seismic response. Comparatively less attention has been paid to the influence of internal masonry partition walls on the global modal characteristics of low-rise residential buildings with masonry load-bearing systems. Moreover, the practical consequences of omitting such walls from finite element models used in routine dynamic analyses require further investigation.

The objective of this study is therefore to determine the influence of internal masonry partition walls on the dynamic characteristics of a detached single-family building with a usable attic. Two finite element models are compared: a baseline model containing the principal load-bearing structure, floor slab, and roof, and an extended model additionally incorporating the masonry partition walls located on the ground floor. The first five natural frequencies and their associated mode shapes are analyzed. Particular attention is given to the magnitude and directional variation of the changes produced by the partition walls. The results are intended to demonstrate whether the omission of nominally non-structural walls may lead to an underestimation of the global stiffness of a low-rise building and, consequently, to an inaccurate evaluation of its dynamic characteristics.

2. Dynamic Analysis of the Building

2.1 Technical and Structural Description of the Analyzed Building

The subject of the study is a detached single-family residential building with a usable attic. It has a simple, compact form and is covered by a gable roof with a rafter-and-collar-beam structural system. The building is located at 4 Polna Street in Zawichost. Its plan has a regular geometry with external dimensions of 8.50 × 10.00 m. The maximum height from ground level to the roof ridge is 8.29 m (Fig. 1).

Fig. 1. View of the analyzed building

The primary load-bearing system comprises masonry walls and a reinforced-concrete floor slab. The external and internal load-bearing walls are made of MAX hollow clay blocks, 29 and 25 cm thick, respectively, laid in M5 cement mortar. The building is founded on strip footings made of C12/15 concrete, with their bases located 1.7 m below ground level. The floor above the ground floor was designed as a 12-cm-thick reinforced-concrete slab made of C20/25 concrete. The roof structure is a traditional timber rafter-and-collar-beam system made of C30 pine. The load-bearing roof members have rectangular cross-sections: 10 × 18 cm rafters spaced at 80 cm, 8 × 16 cm collar beams, and 14 × 14 cm wall plates. The wall plates are anchored directly to the reinforced-concrete ring beams of the external ground-floor walls.

The internal partition walls on the ground floor were constructed using traditional masonry technology from 12-cm-thick Category I hollow clay blocks with f_b = 10.15 MPa, laid in M5 cement-lime mortar. They separate the building into individual functional zones. Table 1 summarizes the material properties adopted in the numerical analysis for the foundations, floor slab, load-bearing walls, and partition walls according to procedure established in [11]. The actual geometry and arrangement of these partitions at the individual levels are shown in the architectural and structural plans (Fig. 2), while the vertical structural system and height geometry of the building are illustrated in the vertical section (Fig. 3).

Tab. 1. Material properties adopted in the model of the analyzed building

Material	Young's modulus E [GPa]	Poisson's ratio ν [-]	Mass density ρ_m [kg/m³]
Foundation	27	0.17	2453
Floor slab	30	0.17	2453
Load-bearing walls	2.5	0.25	900
Partition walls	1.5	0.25	800

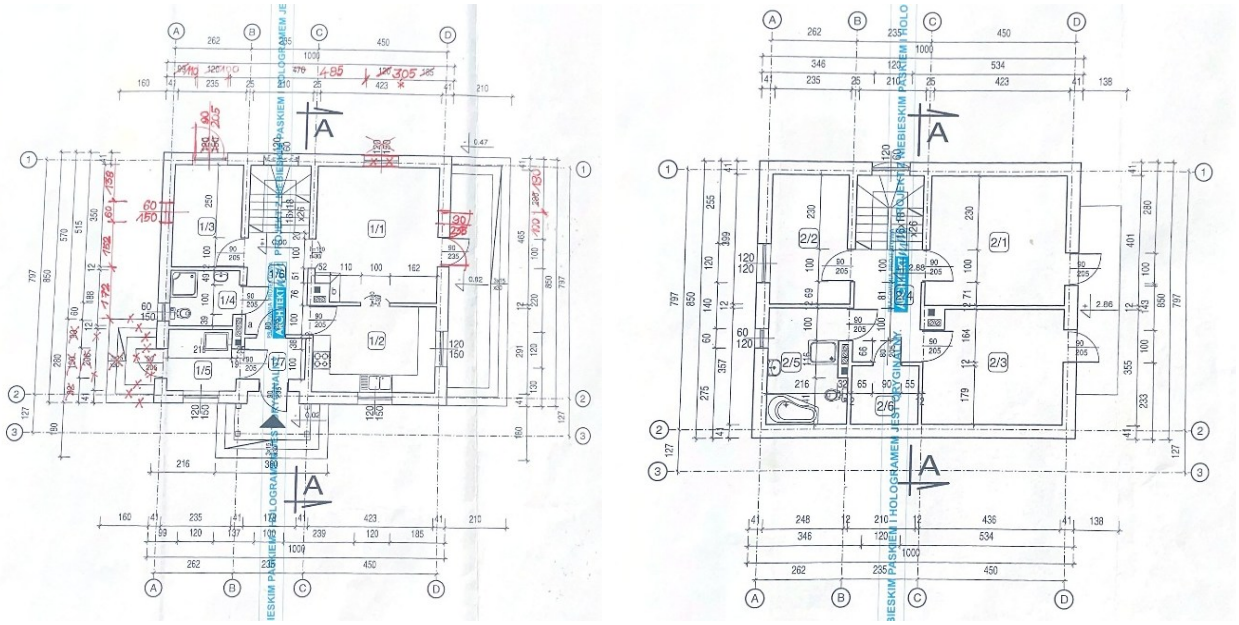

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Fig. 2. Architectural and structural plans of the analyzed building: a) ground-floor plan, b) usable-attic plan

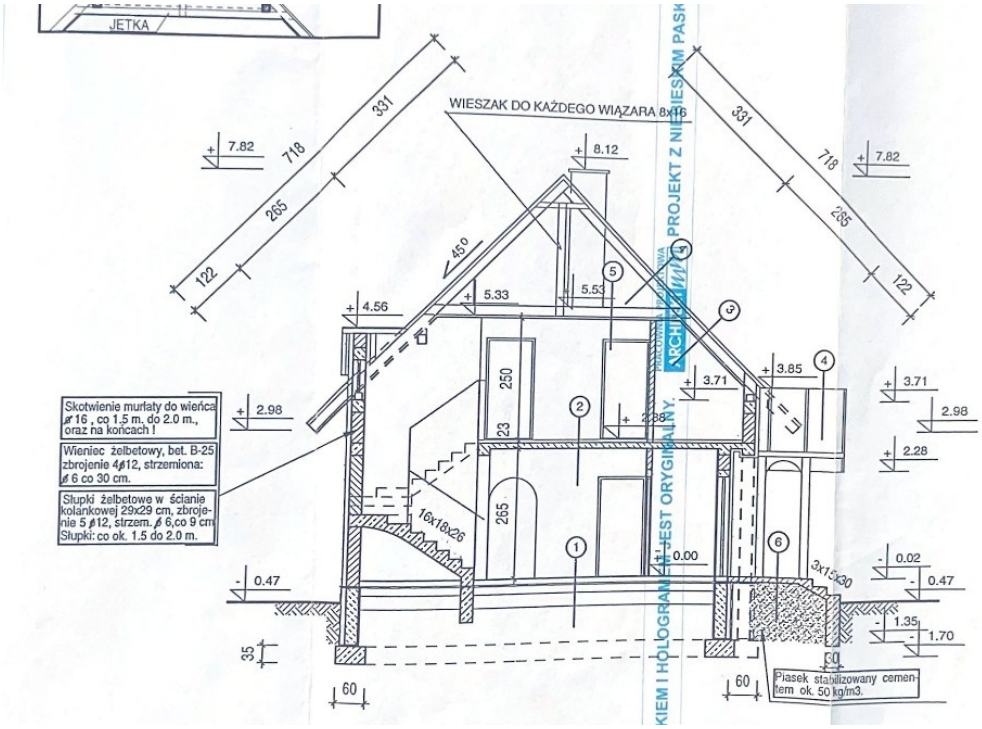

Fig. 3. Vertical section of the analyzed building

2.2 Description of the Numerical Model

Although partition walls are conventionally treated in structural design solely as an additional load and mass, their full and tight contact with the reinforced-concrete slab and the floor causes them to act in practice as vertical stiffening panels. They restrain deformation of the ground-floor slab and affect the distribution of stiffness and mass throughout the building.

To assess the influence of non-structural elements on the dynamic behavior of the building, a three-dimensional numerical model was developed using the finite element method (FEM). The dynamic analysis was performed in Autodesk Robot Structural Analysis Professional, enabling the interaction between the primary load-bearing system and the masonry partition walls on the ground floor to be accurately represented. The boundary conditions at foundation level represented the elastic interaction between the structure and the subsoil using one-parameter spring elements.

To clearly demonstrate the difference in structural behavior, two variants were analyzed: a baseline model comprising the load-bearing system, floor slab, and roof without partition walls, and an extended model supplemented with the partition walls described above. An identical finite element mesh with a target element size of 0.25 m was applied in both cases, enabling a direct and reliable comparison of the resulting modal parameters. Discretization was performed using the complex meshing method (Delaunay) with an enforced regular mesh and four-node quadrilateral surface elements. This ensured full nodal compatibility along the interfaces between the individual wall panels and the floor slab [12]. The geometry of both numerical variants is shown in Fig. 4.

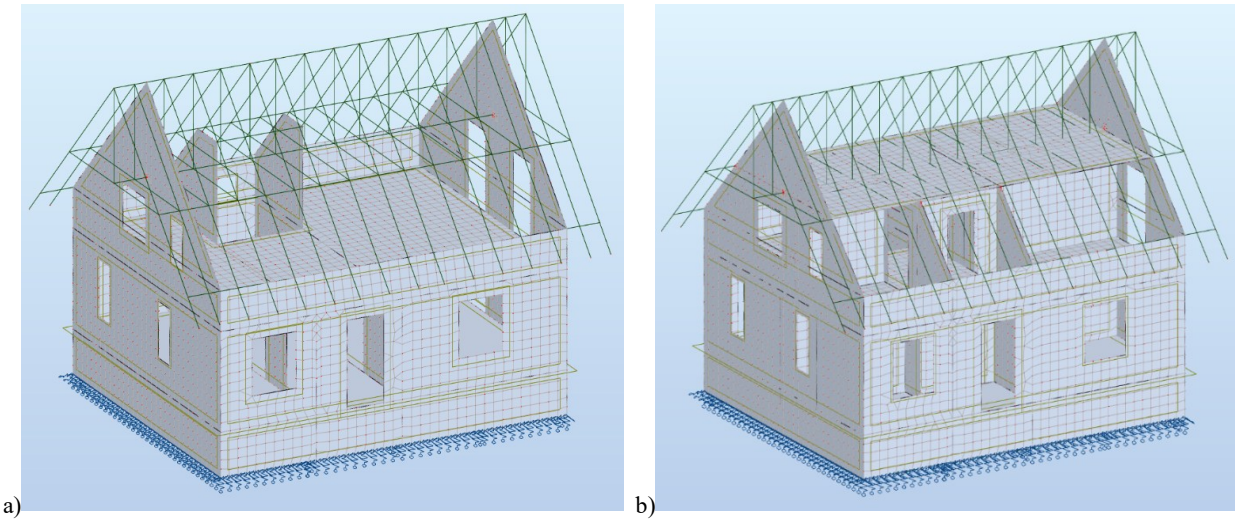

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Fig. 4. Finite element models of the analyzed building: a) baseline model, b) extended model

2.3 Modal Analysis Results and Dynamic Parameters

To assess the influence of non-structural elements on the dynamic properties of the building, the modal parameters obtained for the baseline and extended models were compared. The analysis covered the first five modes, for which the natural frequencies were determined. Both models were subjected to modal analysis to determine the natural frequencies and the corresponding mode shapes of the structure (Table 2).

Tab. 2. Comparison of natural frequencies between the baseline and extended models

Mode No.	Baseline model	Model including non-structural elements	Difference
1	5.92 Hz	8.04 Hz	35.81%
2	8.74 Hz	8.97 Hz	2.63%
3	9.55 Hz	10.30 Hz	7.85%
4	11.37 Hz	13.00 Hz	14.34%
5	15.42 Hz	15.93 Hz	3.31%

The results presented in Table 2 indicate that including the non-structural elements produces varying increases in the natural frequencies. The sharp 35.81% increase for the first mode results from the predominant stiffness contribution of walls oriented along the X-axis, whereas in the transverse direction (Y-axis), the additional mass of the partitions almost completely offsets their minor stiffening effect.

The natural frequencies of buildings are influenced by several physical and structural parameters. The most important include the stiffness of the structural system, mass distribution, boundary conditions, and geometric proportions of the building. An increase in element stiffness directly raises the natural frequencies, whereas an increase in mass lowers them. Stiffer elastic supports at foundation level and a more compact building geometry also result in higher modal frequencies.

The first three dominant mode shapes for both analyzed structural variants are compared in Figs. 5–7. These visualizations show typical global deformation patterns associated with the fundamental translational and torsional responses of the system, allowing the influence of non-structural elements on the form of these deformations to be assessed directly.

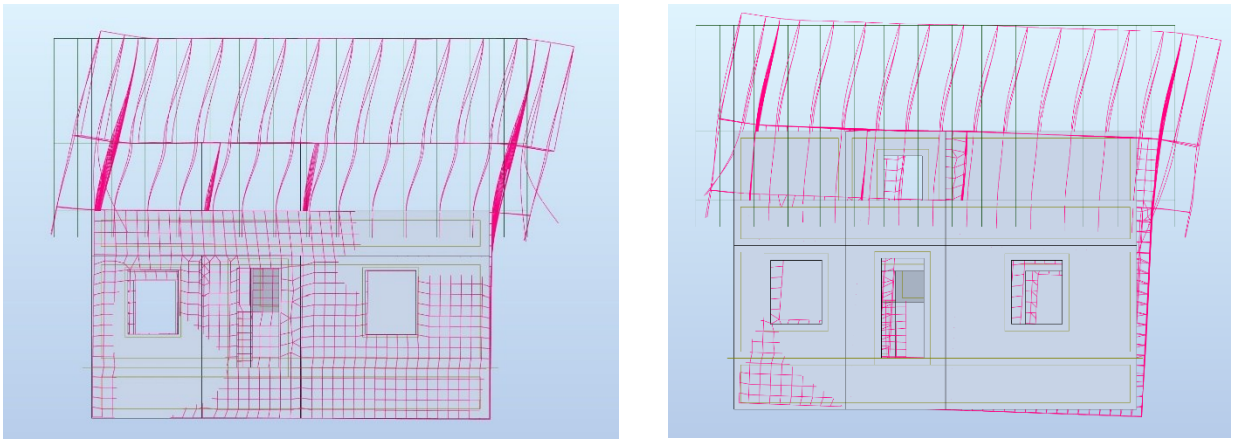

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Fig. 5. First mode shape of the analyzed building: a) baseline model, b) extended model

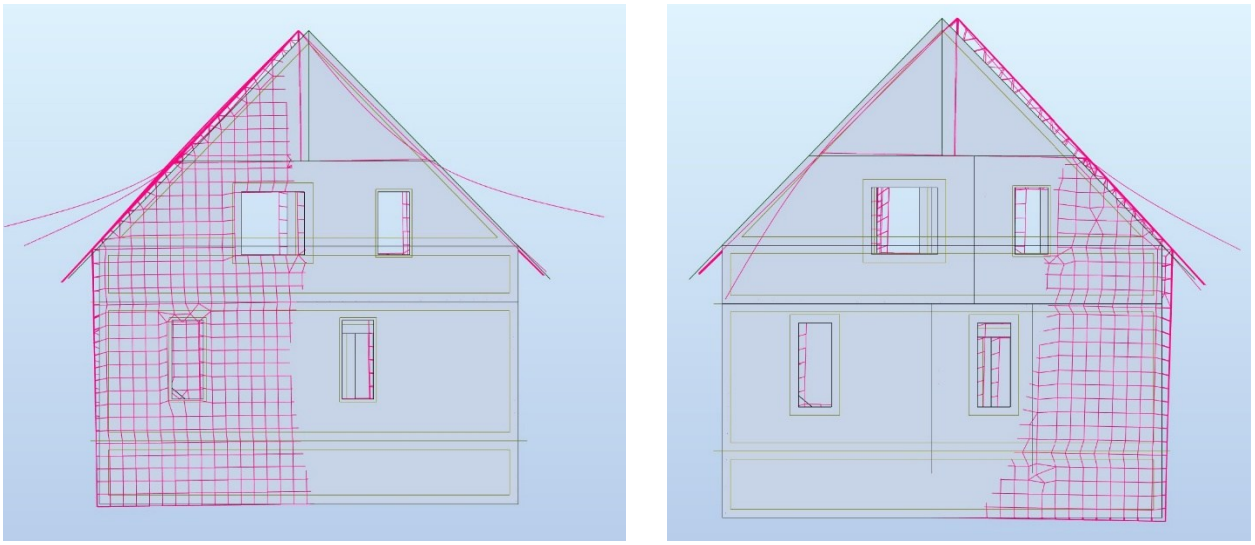

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Fig. 6. Second mode shape of the analyzed building: a) baseline model, b) extended model

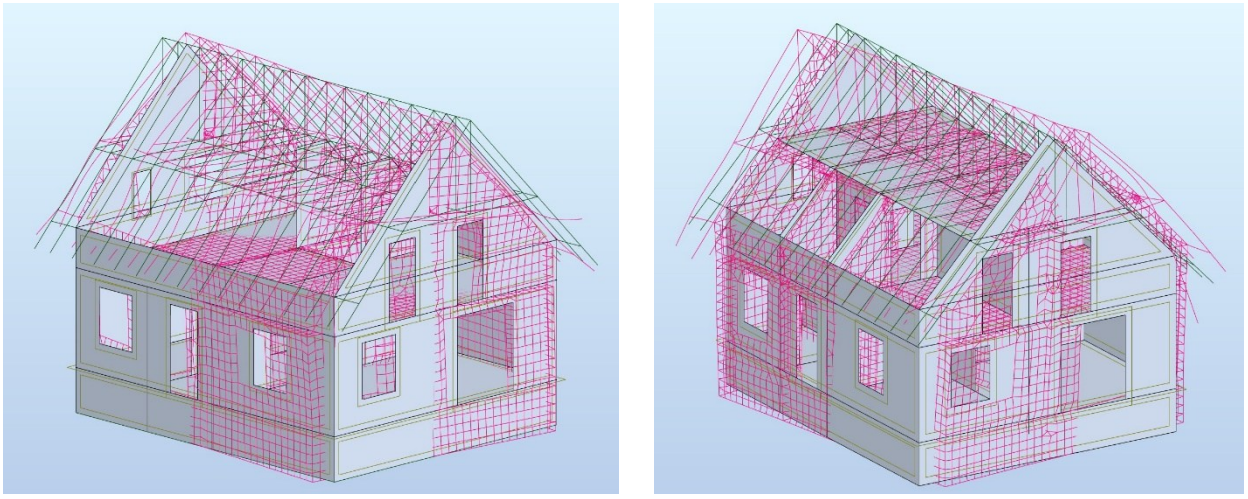

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Fig. 7. Third mode shape of the analyzed building: a) baseline model, b) extended model

A comparative analysis of the visualizations presented in Figs. 5–7 demonstrates the modal stability of the analyzed system. Although the inclusion of non-structural elements noticeably affected the frequency values, it did not change the character or order of the individual mode shapes. In both the baseline and extended models, the first mode remains predominantly translational along the X-axis (Fig. 5), the second corresponds to translation along the Y-axis (Fig. 6), and the third represents a torsional mode of the structure (Fig. 7). This confirms that the global dynamic behavior of the building is preserved despite the local stiffening introduced at individual levels.

3. Conclusions

Including non-structural elements in the dynamic model produced an increase in the natural frequencies of all analyzed modes, ranging from 2.63% to 35.81%. Although the introduction of masonry partition walls also increased the total vibrating mass of the building, the accompanying increase in structural stiffness was the dominant factor. Consequently, omitting these elements from the numerical model leads to an underestimation of the effective stiffness of the structural system and may result in an inaccurate assessment of the building's dynamic behavior. This is particularly important when the calculated modal parameters are subsequently used to predict structural response or evaluate vibration serviceability.

The increase in stiffness was strongly directional, reflecting the geometric arrangement of the partition walls in plan. The largest differences in natural frequencies were recorded for modes involving motion along the X-axis. Most of the partition walls are oriented parallel to this axis and therefore provide considerably greater resistance to deformation in this direction. Their stiffening contribution thus depends not only on their mechanical properties but also on their number, location, and spatial orientation. These factors should be represented appropriately to reproduce the actual dynamic behavior of the building in a numerical model.

Despite the substantial changes in the frequency values associated with motion along the X-axis, the corresponding mode shapes retained their original geometric character. The dominant translational motions along the principal axes and the torsional mode were neither reordered nor qualitatively modified. This indicates that the partition walls increased the modal stiffness without changing the principal global deformation mechanisms of the building. Their inclusion therefore affected primarily the numerical values of the natural frequencies rather than the overall modal structure.

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