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EFFECT OF THE STRUCTURAL INTERACTIONS IN MULTI-STORY CLT SHEAR WALLS

E. M. Ruggeri[1], **G. D'Arenzo**[2], **M. Fossetti**[3]

[1] Faculty of Engineering and Architecture, Kore University of Enna, Italy
e-mail: e-mail: elisabettamaria.ruggeri@unikorestudent.it

[2] Timber Structures and Building Rehabilitation, University of Kassel, Germany
e-mail: giuseppe.darenzo@uni-kassel.de

[3] Faculty of Engineering and Architecture, Kore University of Enna, Italy
e-mail: e-mail: marinella.fossetti@unikore.it

Abstract

A CLT platform building is made up of horizontal and vertical panels, which are assembled on site to obtain a "box-type" structure, in which the lateral load resisting system consists of the assembly of different shear walls with their base connections, and other typologies of connections. The lateral behavior of a CLT platform building is governed by the wall base connections, but also influenced by different structural interactions including those between floor and wall segments and those between lintels and wall segments. The magnitude of the interactions between lintels and wall segments depends on the construction technique chosen for creating the openings, which can be realized through monolithic or assembled shear walls. Although multi-story CLT shear walls realized with these two different construction techniques exhibit a different lateral behavior, often, the same simplified modelling strategy is considered in the design practice, neglecting relevant aspects of the lateral behavior such as the structural interactions. This paper investigates in detail the differences of the lateral behavior of multi-story CLT shear walls realized with these two construction techniques by considering both simplified modelling strategies and more advanced modelling strategies, which consider the structural interactions between floor diaphragms and wall segments and between lintels and wall segments. Results of nonlinear static analyses showed significant differences between the two modelling strategies in terms of lateral performance and failure modes of the systems, emphasizing that simplified modelling strategies cannot always be reliable methodologies to describe the behavior of multi-story CLT shear walls.

Keywords: CLT structures, multi-story shear walls, structural interactions, numerical modelling strategies, lateral capacity.

1 INTRODUCTION

Typically, in the design of a CLT building, it is assumed that the mechanical behavior of the shear walls is primarily governed by the mechanical properties of the panels and connections at the base of the wall. Based on this assumption, several analytical models that predict the lateral stiffness and lateral capacity of a CLT wall subjected to lateral loads were developed, see for instance [1]. CLT buildings, especially those built using the platform construction technique, have a significant structural redundancy because of the multiple connections between the exterior walls, interior partitions, and floor diaphragms. The lateral performance of a building constructed using the platform method is strongly influenced by the connection details. Moreover, the type of connection determines how lateral forces are transferred from the floors to the walls and thus to the foundation. In this context, in case of platform CLT buildings, in addition to the connections placed at the base of the walls (hold-downs and angle brackets), there are other connections that influence the mechanical behavior of CLT shear walls, such as those between perpendicular walls and between floors and walls.

The effects of interaction between horizontal floors and vertical walls have been found in several experimental tests of CLT buildings, see for instance the study by Popovski and Gavrić [2] and Yasumura et al. [3], as well as in analytical and numerical studies. D'Arenzo et al. [4] presented a study on the phenomenon of the floor-to-wall interaction and on its influence on the rocking behavior of segmented CLT shear walls. Results of this study showed that the floor-to-wall interaction increases the rocking stiffness of segmented shear walls and modifies the kinematic behavior of these systems. Tamagnone et al. [5] analyzed the influence of the out-of-plane stiffness of the floor diaphragm and floor-to-wall connections on the rocking behavior of segmented CLT walls. Results of this study showed that the stiffness of the floor-to-wall connections has a strong influence on the lateral behavior of the system, which modify the behavior of the panels. Gavrić et al. [6] and Ruggeri et al. [7] investigated the effects of the interactions between perpendicular walls in "box-type" CLT buildings. These studies showed that the properties of the hold downs of the perpendicular walls and the wall-to-wall connections between the shear walls and the perpendicular walls contribute to increase the lateral performances of CLT structures.

Since the lateral response of a CLT building depends on different structural interactions, the presence of the openings also plays an important role in the lateral behavior of multi-story CLT shear walls. In case of platform construction method, the openings may be realized following two different construction techniques: by cutting out of the CLT panel with an automated process during fabrication, or by assembling multiple CLT panel elements in situ [3,8]. In the first case, it is possible to schematize the system as a monolithic shear wall, whose lateral behavior is influenced by the structural continuity between the wall segments and the lintels, see Figure 1. In the second case, when lintels are assembled by means of mechanical connections to the wall segments (assembled shear wall), the system can be studied considering wall segments as cantilever elements due to the fact that lintels provide very limited interaction, see Figure 1.

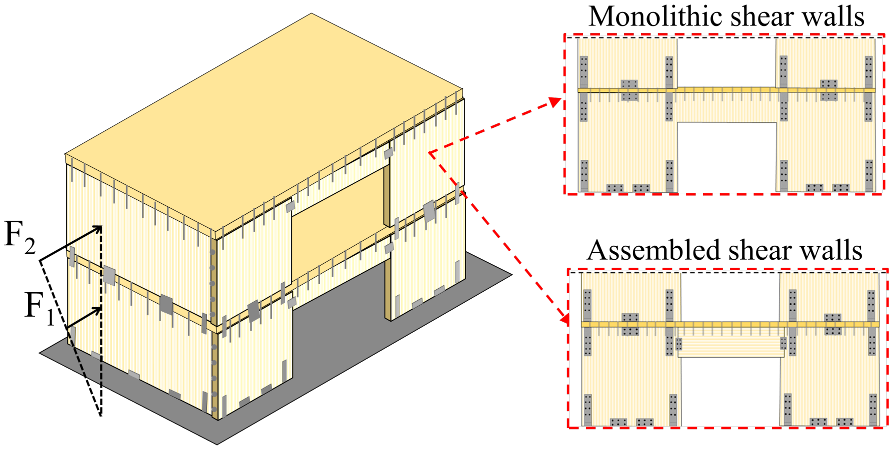


Figure 1: Typical platform CLT building with openings.

The mechanical behavior of CLT shear walls with door and window openings were studied by Casagrande et al. [9] through full-scale experimental tests and numerical analyses. Results of this study showed that, in case of shear wall with openings, the failure may occur in the lintel element either in bending or shear. Mestar et al. [10] studied the kinematic modes of CLT shear walls with openings and observed that the lintel geometry and the vertical stiffness of the wall base connections, govern the lateral behavior of these systems. D'Arenzo [11] investigated the lateral behavior of monolithic shear walls with openings with particular focus on the effects of the interactions between the CLT wall segments, the lintels and the parapets. Results of this study showed that there is an interaction between lintels, parapets and wall segments, which modifies the lateral deformation mechanism and the kinematic modes of the shear walls and lead to higher lateral performances. Similar results were found by Khajehpour et al. [12], who studied the effects of the interactions between lintel, parapets and wall segments in multi-story shear wall systems.

Although the results documented above reveal that the presence of the floor and its connections to the underlying walls and the two different shear wall construction techniques (monolithic and assembled), lead to different lateral behavior of CLT systems, it is common practice in structural design to model multi-story CLT shear walls by considering the same simplified modelling strategy. This modelling strategy considers wall segments and their connections at the base, but neglects the contribution given by the interactions between lintel and wall segments and between floor elements and wall segments [13,14].

To overcome this limitation and realistically simulate the behavior of a CLT structures under lateral loads, it is necessary to implement numerical models that take into account these structural interactions, since they can profoundly influence the lateral response of CLT structures. In this study, two advanced modelling strategies, which consider the structural interactions between floor diaphragms and wall segments and between lintels and wall segments are proposed. The different modeling strategies were applied to the two construction techniques in the presence of openings, see Figure 1. In order to compare the results obtained from the simplified modelling strategy with those obtained from the advanced modelling strategies that take into account the structural interactions, nonlinear static analyses were conducted. Results of the current study will show how the different modelling strategies lead to significantly different lateral performance of the structures in terms of lateral stiffness, capacity and failure modes.

2 MODELLING STRATEGIES

Typically, multi-story CLT shear walls are modelled by means of simplified modelling strategy in the numerical analyses. In this context, the wall segments provide the stability for horizontal loads and are schematized as cantilever elements, while lintels and parapets are modelled as pinned elements and are considered as non-structural components. Hold-downs are placed at both extremities of each wall segment to prevent it from overturning, while angle brackets, that transfer the shear loads to the foundation, are placed along the length of the wall panels. Using this modelling strategy for multi-story CLT shear walls, the bending contribution of floor diaphragms and lintels is neglected, see Figure 2. In this simplified modelling strategy, called SM, the lintels (and parapets) have the function of transferring vertical and horizontal loads to the wall segments [8,15]; as result no bending moment is transmitted between the wall segments and the lintels, and the system failure occurs in the mechanical anchors placed at the base of the wall segments.

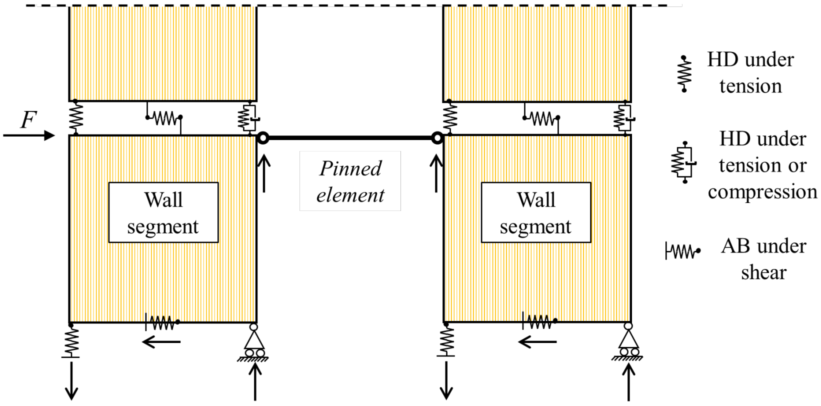


Figure 2: Simplified modelling strategy of multi-story CLT shear walls (SM).

In order to realistically simulate the lateral behavior of a multi-story CLT shear walls, it is necessary to adopt a more advanced modelling strategy, which takes into account the interactions between lintels and wall segments and the interactions between floors and wall segments. In this context, an advanced modelling strategy that consider these structural interactions (IM) is proposed. In particular, this advanced modelling strategy is applied for both monolithic walls (IM-MSW) and assembled walls (IM-ASW).

In case of monolithic shear walls (IM-MSW), see Figure 3, the structural continuity between lintels and wall segments is ensured and the failure of the system can occur either in the connections at the base of the wall segments or in the corner of the openings between the lintel and the wall segments, depending on the level of stresses in this critical zone [2,16,17]. Using this modelling strategy, higher lateral performance can be achieved than the SM strategy due to the fact that the lintels have the ability to transfer bending actions, but also due to the bending contribution of the floor diaphragms. According to D'Arenzo [11] the bending stiffness of monolithic shear walls with openings is governed by the stiffness of the lintels, parapets, hold-downs and it also depends on the geometry of the system. Furthermore, a strong correlation was found between the kinematic behavior and the rocking stiffness of the system, in fact, the kinematic behaviors with a one center of rotation are associated with values of rocking stiffness generally higher than those achieved by the kinematic behaviors with two centers of rotation. Based on the results of this study, in case of monolithic shear walls (IM-MSW), a different lateral deformation mechanism may occur with a different distribution

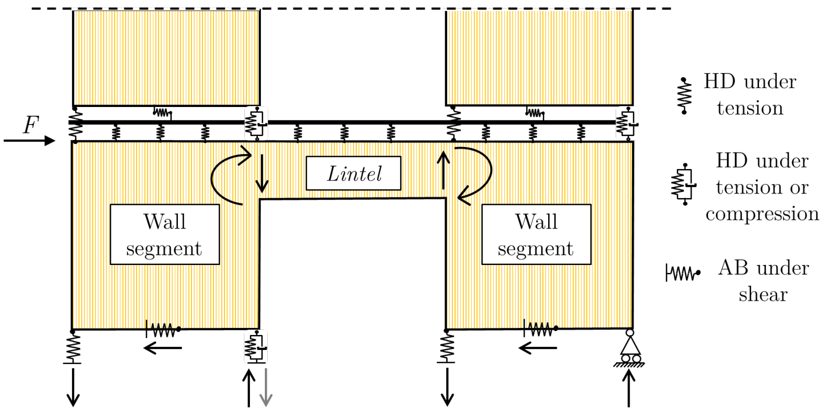


Figure 3: Advanced modelling strategy with interactions of multi-story CLT shear walls (IM-MSW).

of the centers of rotation of the system [18], depending on the bending stiffness and the capacity of lintels and floor diaphragms.

Also in case of assembled shear walls (IM-ASW), see Figure 4, modelled considering the structural interactions, higher lateral performances are expected compared to the SM strategy, due to the bending contribution of the floor diaphragms. Unlike the case of monolithic walls (IM-MSW), in this construction technique it is not possible to obtain full structural continuity between lintels and wall segments with the typical mechanical connections used in practice, and consequently, the failure of the system may occur in the floor panel or in the connections placed at the base of the wall segments.

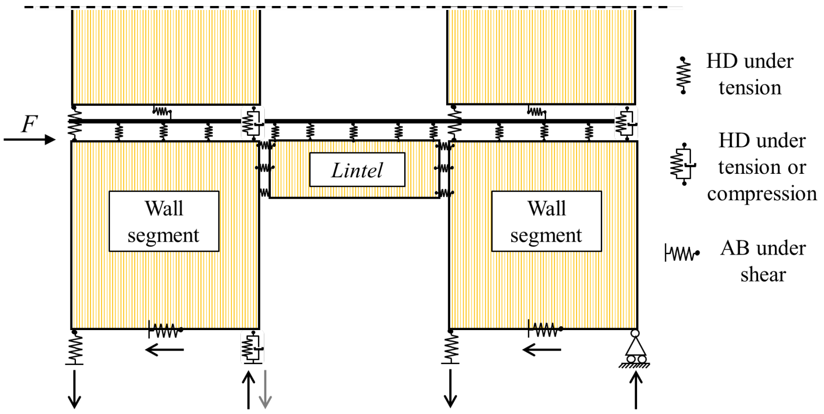


Figure 4: Advanced modelling strategy with interactions of multi-story CLT shear walls (IM-ASW).

In the next sections, the numerical study aimed at investigating the effects of the interactions provided by floor diaphragms, lintels, and wall segments in multi-story CLT shear walls is presented.

3 NUMERICAL STUDY

In the following, the configurations, the mechanical parameters, the numerical modelling, including the failure mode criteria, of different multi-story CLT shear wall systems used for the numerical study are presented.

3.1 Configuration and mechanical parameters

In order to investigate the effects of the two different construction techniques (see Figure 1) and the structural interactions due to floors, lintels, and wall segments the lateral behavior of different CLT multi-story shear wall geometries, with different panel and connection properties were studied. Figure 5 shows the nine different multi-story CLT shear wall configurations and the distribution of the mechanical anchors used in this study. These structures consist of one-, three-, and five-story systems and three different geometries, with a lintel height of 400 mm. For all stories and for all geometries, the same CLT wall segment height and the same CLT floor thickness were assumed. The geometrical dimensions of the three different geometries are shown in Figure 6.

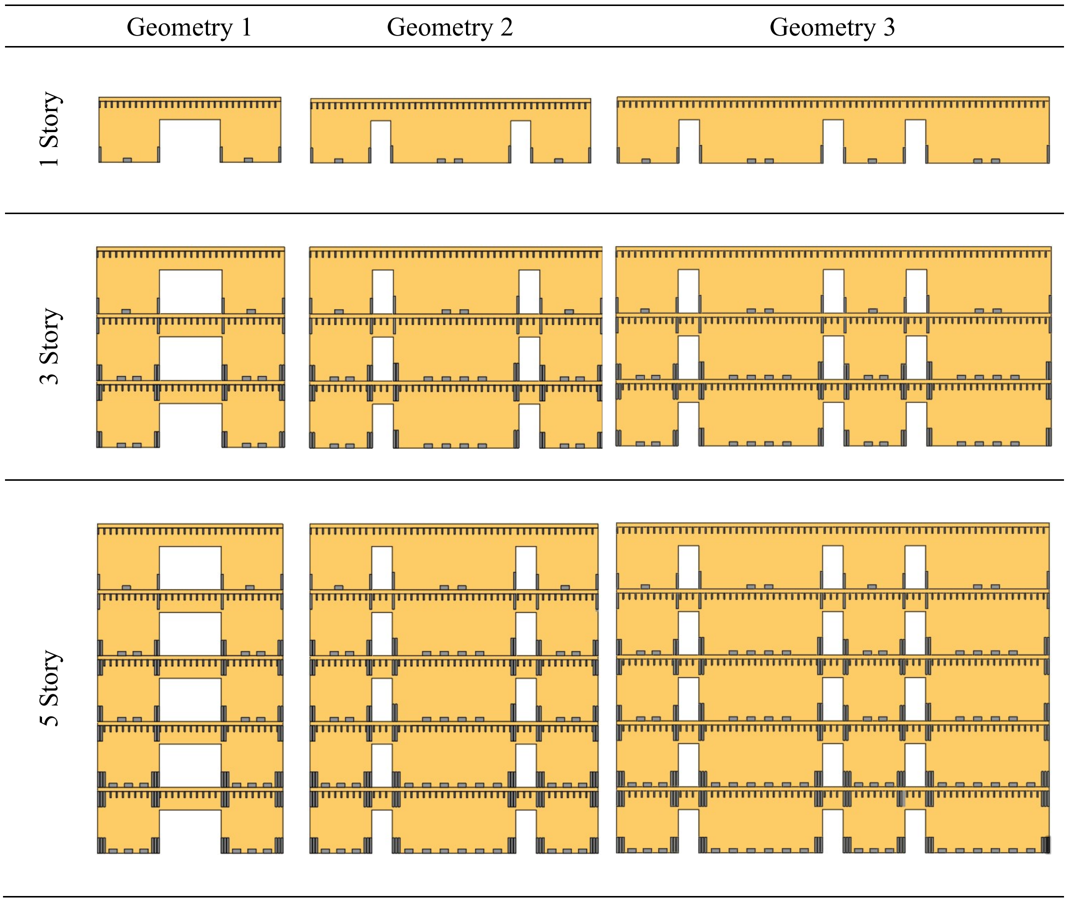
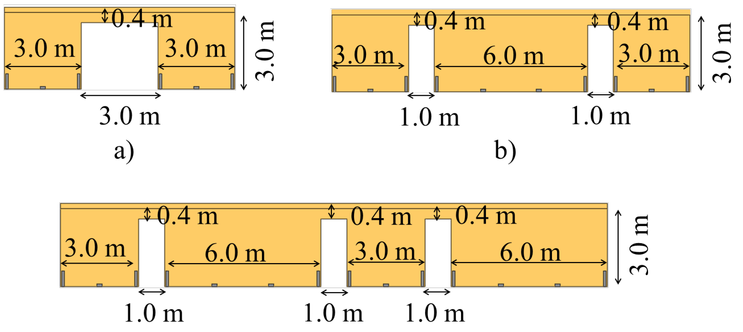


Figure 5: Multi-story CLT shear walls configurations and connections distribution.



a)

b)

c)

Figure 6: CLT shear walls geometries and dimensions: a) Geometry 1, b) Geometry 2 and c) Geometry 3.

The numerical study was conducted by considering three different thicknesses of CLT wall panels along the height of the structures, as is usually done in the practical construction of multi-story CLT buildings. Figure 7 shows the different layer's thicknesses for the Floor panel (FP), the same for all stories, and for the Wall panel 1 (WP1), Wall panel 2 (WP2) and Wall panel 3 (WP3), used along the height of the structures. Depending on the construction technique, a different direction of the external wooden laminates was assumed for the wall segments and lintels. In case of monolithic shear walls, the orientation of the external wooden laminates of CLT panels was assumed to be in the vertical direction for both wall segments and lintels, while in case of assembled shear wall, a vertical orientation was assumed for wall segments and a horizontal orientation was assumed for lintels. The distribution of the different CLT panels considered along the height of the structures are shown in Table 1.

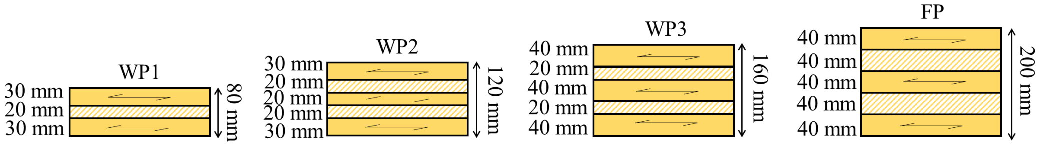


Figure 7: Layers thicknesses.

CLT panels thickness [mm]			
	1 story	3 story	5 story
Fifth story			WP1
Fourth story			WP2
Third story		WP1	WP2
Second story		WP2	WP3
First story	WP1	WP2	WP3

Table 1: Distribution of the CLT panel sections along the height of the structures.

The modulus of elasticity parallel to the grain, E_0, perpendicular to the grain, E_{90}, and the in-plane shear modulus G_0 of the wooden laminates of all CLT panels were assumed to be 11700 MPa, 390 MPa and 730 MPa, respectively. The mechanical properties of the connections at the base of the shear walls, hold-downs and angle brackets, were chosen on the basis of the experimental results of Casagrande et al [19]. In this study, the WHT440 type hold-downs with thirty 4×60 mm annular ring nails and the TTF200 type angle brackets with thirty 4×60 mm annular ring nails were tested for tension and shear loads, respectively. On the basis of these results, the values of vertical elastic stiffness and maximum strength of a hold-down were set respectively equal to 6.61 kN/mm and 78.14 kN, while the values of horizontal elastic stiffness and maximum strength of an angle bracket were set equal to 8.94 kN/mm and 70.04 kN, respectively. The number of the mechanical anchors of the CLT multi-story shear walls was set considering the increase of the shear force from the upper stories to the foundation. In fact, a different number of hold-downs along the height of the structures, placed at the ends of each wall segment, and a different number of angle brackets, distributed along the base of the wall segments, were considered (see Figure 5). The mechanical properties of one hold-down and one angle bracket used for the numerical analyses are summarized in Table 2.

	K_{el} [kN/mm]	F_y [kN]	F_{max} [kN]	F_{ult} [kN]	v_y [mm]	v_{max} [mm]	v_{ult} [mm]	D [-]
Hold-down	6.61	61.33	78.41	62.51	9.28	18.87	28.47	3.07
Angle bracket	8.94	57.69	70.04	56.03	6.45	16.26	26.07	4.04

Table 2: Parameters of the base connections used for the numerical analyses.

Mechanical properties of the floor-to-wall connections were assigned based on the experimental results of Gavric et al.[20]. Based on this study, the withdrawal stiffness (vertical direction) and the shear stiffness (horizontal direction) of one screw was set equal to 4.00 and 1.45 kN/mm, respectively. The spacing between each wall-to-wall connection is chosen equal to 300 mm in all analyses. A vertical load q equal to 10 kN/m was applied on each story of the system, while a triangular distribution of horizontal loads F was adopted. The value of the base shear force used in each configuration are reported in Table 3.

	Base shear [kN]		
	Geometry 1	Geometry 2	Geometry 3
1 story	21.4	33.3	50.0
3 story	128.6	200.0	300.0
5 story	321.4	500.0	750.0

Table 3: Base shear used for each configuration.

3.2 Description of the numerical modelling

Numerical models were developed using the software package SAP2000 [21]. Orthotropic homogeneous shell elements [22] were adopted to reproduce the wall segments and the lintels considering the different thicknesses of the CLT panels. Effective modulus of elasticity in the vertical, $E_{eff,v}$, and horizontal, $E_{eff,h}$, direction of the panel were assigned considering the layered distribution of the different CLT panel sections, according to the composite theory of Blaß and Fellmoser [23]. Whereas, the effective in-plane shear modulus of the wooden laminates, G_{eff}, was defined according to Bogensperger et al. [24]. The mechanical properties of the CLT panels used in the numerical models (WP1, WP2, WP3) are summarized in Table 4.

Quadrilateral shell elements with a mesh size equal to 100×100 mm were adopted in all numerical analyses. In case of SM strategy, the pinned elements connecting the wall segments were modeled as frame elements, see Figure 8.

	$E_{eff,v}$ [MPa]	$E_{eff,h}$ [MPa]	G_{eff} [MPa]
WP1	8872	3217	573
WP2	7930	4160	598
WP3	8872	3217	570

Table 4: Mechanical properties of CLT panels.

In case of structures analyzed with the modelling strategies with interactions (IM strategy), the floor diaphragms were modelled as beam elements with effective bending stiffness E_0I_{eff}. The effective moment of inertia I_{eff} was calculated considering the layered structure of the panel and in particular the thickness of each layer, the distance of each layer from the centroid of the section, and the floor width. The calculation of the floor width relied on the method presented by Masoudnia et al [25] for determining the effective collaborative section in situations of internal bending actions. Based on this, the effective bending stiffness of the floor was set equal to 5793 kNm^2.

In case of monolithic shear wall analyzed with the advanced modelling strategy taking into account the structural interactions (IM-MSW), wall segments and lintels were modelled as unique shell element with the same orientation of the external wooden laminates (z), see Figure 9 (a). Whereas, in case of assembled shear walls analyzed considering the effect of the interactions (IM-ASW), wall segments and lintels were modelled as separate shell elements with different orientation of the external wooden laminates (z and x, respectively) and connected by means of wall-to-lintel connections (w-l), see Figure 9 (b).

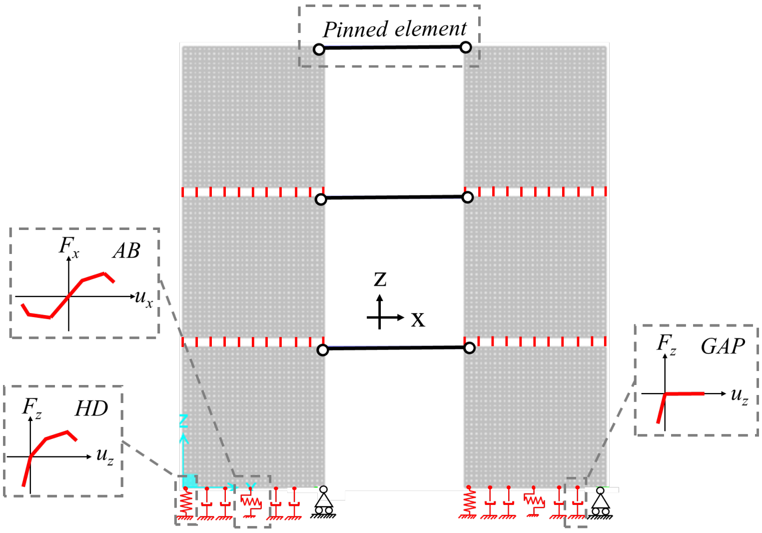
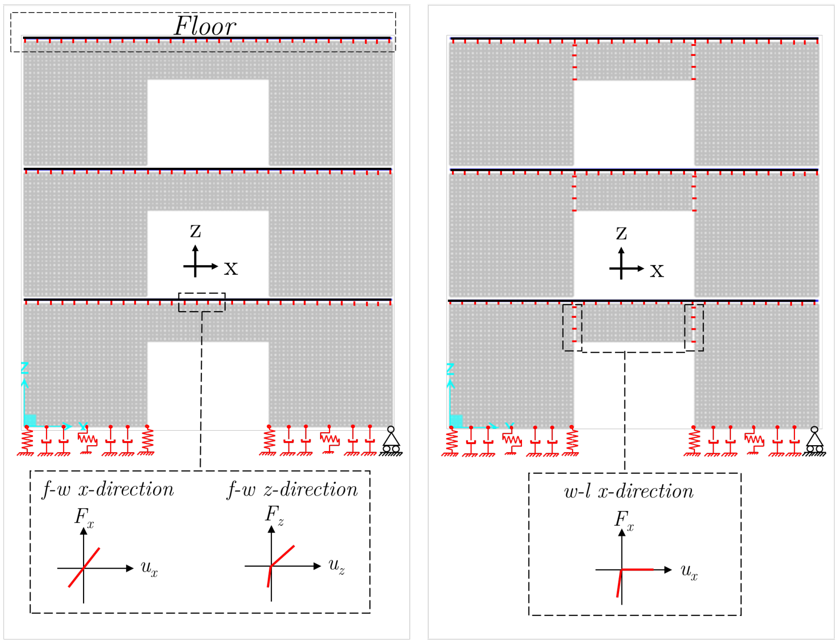


Figure 8: Simplified modelling strategy of multi-story CLT shear walls (SM).

In case of simplified modelling strategy, the analyses were conducted applying the horizontal forces F on the top of wall segments at each story, while a vertical load q was applied on the first row of shell elements of the walls and on the pinned elements as equivalent load per unit area and as uniformly distributed load, respectively. While, in case of advanced modelling strategies with interactions, the horizontal forces F were applied on the top of the wall segments at each story and a vertical load q was applied to the first row of shell elements of the walls as equivalent load per unit area.



a) b)

Figure 9: Advanced modelling strategy with interactions: a) of monolithic(IM-MSW). and b) assembled multi-story CLT shear walls (IM-ASW).

Hold-downs and angle brackets (HD and AB, respectively) were modelled by means of one- and two-joint multilinear elastic links, for both modelling strategies, SM and IM. The hold-downs were characterized by different multilinear behavior for tensile and compressive forces: for tensile forces the tensile stiffness of the hold-downs was considered, while for compressive forces the link simulated the contact between panel and foundation through high stiffness values, see Figure 8. The vertical tensile behavior (z) of the hold downs was modelled with a trilinear curve according to the values reported in Table 2. Angle brackets were modelled with symmetrical tri-linear curve in the horizontal shear direction (x), in order to reproduce the nonlinear behavior of the angle brackets for shear loads, see Figure 8.

To simulate the contact between the wall segments and the foundation, gap elements with rigid compression-only behavior were defined for both modelling strategies, SM and IM, see Figure 8. These gap elements were also used between the wall segments of the different stories in the SM strategy.

In the IM strategy, the floor-to-wall connections (f-w) were modelled as a series of two-joint multilinear elastic links from the SAP2000 library, see Figure 9. These connections were characterized by a symmetric elastic behavior in the horizontal shear direction (x), while they were modelled with elastic behavior, for tensile loads, in order to simulate the withdrawal behavior of the connection, and with a stiff behavior, for compressive loads, to simulate the contact between floor and wall. Finally, in case of assembled shear wall (IM-ASW) the wall-to-lintel connections (w-l) were modelled as a series of multilinear elastic two-joint links with stiff compression-only properties in the horizontal (x) direction in order to reproduce the contact between the wall segments and the lintels, see Figure 9.

Results obtained from the modelling strategies that consider the structural interactions (IM-MSW and IM-ASW) were compared with those obtained from the SM strategy and with another additional numerical model that represents a comparison system. This comparison model, called CS, considers the same multi-story CLT shear wall configurations without openings modelled according to the IM strategy, see Figure 10. SM and CS strategies represent respectively the case of maximum and minimum lateral flexibility, while the modelling strategies with interactions in case of monolithic and assembled shear wall (IM-MSW and IM-ASW) should have lateral flexibility between these two cases.

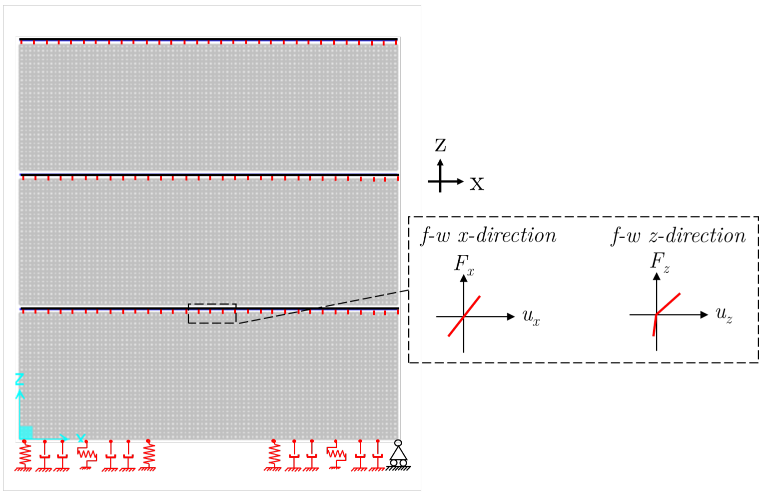


Figure 10: Advanced modelling strategy with interactions in case of multi-story CLT shear walls without openings (CS).

3.3 Failure modes of the systems

CLT shear wall systems are composed of massive timber walls that are fastened together to form "box-type" structures. Due to the high in-plane stiffness of the CLT panels, the lateral response of such systems strongly depends on the connection properties. In fact, in case of shear walls without openings, the failure of the CLT panel is unlikely because it is typically preceded by the failure of the connections. Whereas, in case of monolithic shear wall systems with openings, the high concentrations of forces in the corners of the openings may cause brittle failures of the wooden panel in this critical zone before the failure of the connections take place. This failure type occurs when the strength of the wooden panels in this region is exceeded, involving the formation of cracks around the corner of the openings.

In case of systems with monolithic shear walls (IM-MSW), the failure condition was determined by checking step-by-step in the nonlinear analysis the level of the internal stresses of the panel in the corner around the openings. This verification was performed by verifying the shear (τ) and the horizontal and vertical normal (σ_h and σ_v) stresses of each mesh along the critical region above the corner of the openings, between lintels and wall segments. In particular, in case of monolithic shear walls, the verification was done using the RVSE model, according to Bogensperger et al. [24].

In case of assembled shear walls (IM-ASW), bending failure of the CLT floor panel above the corner of the openings is likely to be observed, according to Yasumura et al. [16]. On the other hand, no failure takes place in the CLT shear walls due to the discontinuity between lintels and wall segments. In these systems, the floor failure was monitored by verifying step-by-step in the nonlinear analysis that the floor bending stresses did not exceed the bending strength of the CLT floor panels. The bending strength of the floor panel was calculated considering the bending strength of the CLT and the effective inertia of the CLT floor panel.

In all numerical modelling strategies considered in this study, the failure of the wall base connections, hold-downs and angle brackets, was monitored considering their ultimate displacement, which is given in Table 2.

4 RESULTS AND DISCUSISON

The influence of the interactions provided by the bending contribution of the floor diaphragms and the structural continuity between lintels and wall segments on the lateral behavior of one- and multi-story CLT shear walls is shown in this section. Nonlinear static analyses were performed, considering the geometry and the connection properties of the systems shown in Figure 5. The results of the nonlinear static analyses in terms of lateral performances and failure modes are presented below. In all analyses conducted in this study, the results obtained from the advanced modelling strategy (IM-MSW and IM-ASW), which takes into account the structural interactions, were compared with those obtained from the structures modelled with the simplified modelling strategy (SM), and the additional numerical model representing a comparison system (CS), which considers the same configurations of multi-story CLT shear walls without openings.

Figure 11 shows the pushover curves and the failure modes of the multi-story CLT shear walls, plotting graphs organized in matrix form. Each graph shows four curves, each one representing the results of multi-story CLT shear walls modelled with one of the four modelling strategies discussed above. The results of the nonlinear analyses show that the pushover curves of the multi-story CLT shear walls obtained from the modelling strategies with interactions (IM-MSW and IM-ASW) are between those obtained from the SM and CS strategies. From Figure 11, it can be observed that when the structural interactions are taken into account, the lateral behavior of the systems is close to that of a structure composed of the same shear walls without openings, which in this study is represented by the comparison system (CS). The exception to this is the Geometry 1, in three- and five-story, in which a behavior between SM and CS strategy is detected. Generally, these results emphasize the significant effect of the structural interactions on the lateral behavior of the multi-story CLT shear walls, meaning that the contribution provided by floors and lintels strongly influences the lateral response of these systems.

For each analyzed case, the failure modes of the systems were investigated, which can occur in the connections placed at the base of the wall segments (hold-down, HD, and angle brackets, AB), in the ends of the lintel elements (critical region), or in the floor section, as described in section 3.3. In the case of systems with monolithic shear walls, failure occurred in the lintel ends. However, it should be noted that the failure of the lintel ends does not represent the failure of the whole structural system, see for instance [26]. In fact, in this circumstance, it is expected that the failure of the lintels leads to a discontinuity between lintel and wall segments and to an overall behavior of the system as that of a multi-story assembled shear walls. On the other hand, in the case of the systems with assembled shear walls, the failure was reached in the wall base connections, while floor section failures never occurred.

Figure 11 shows that, in the case of one-story systems, the pushover curves obtained from each modelling strategy achieve approximately the same lateral stiffness and lateral capacity. This is due to the fact that the systems deform with a predominant sliding mechanism and low rocking, generating negligible structural interactions. As a consequence, shear failure of angle brackets was the failure mode of the one-story systems in all modelling strategies considered.

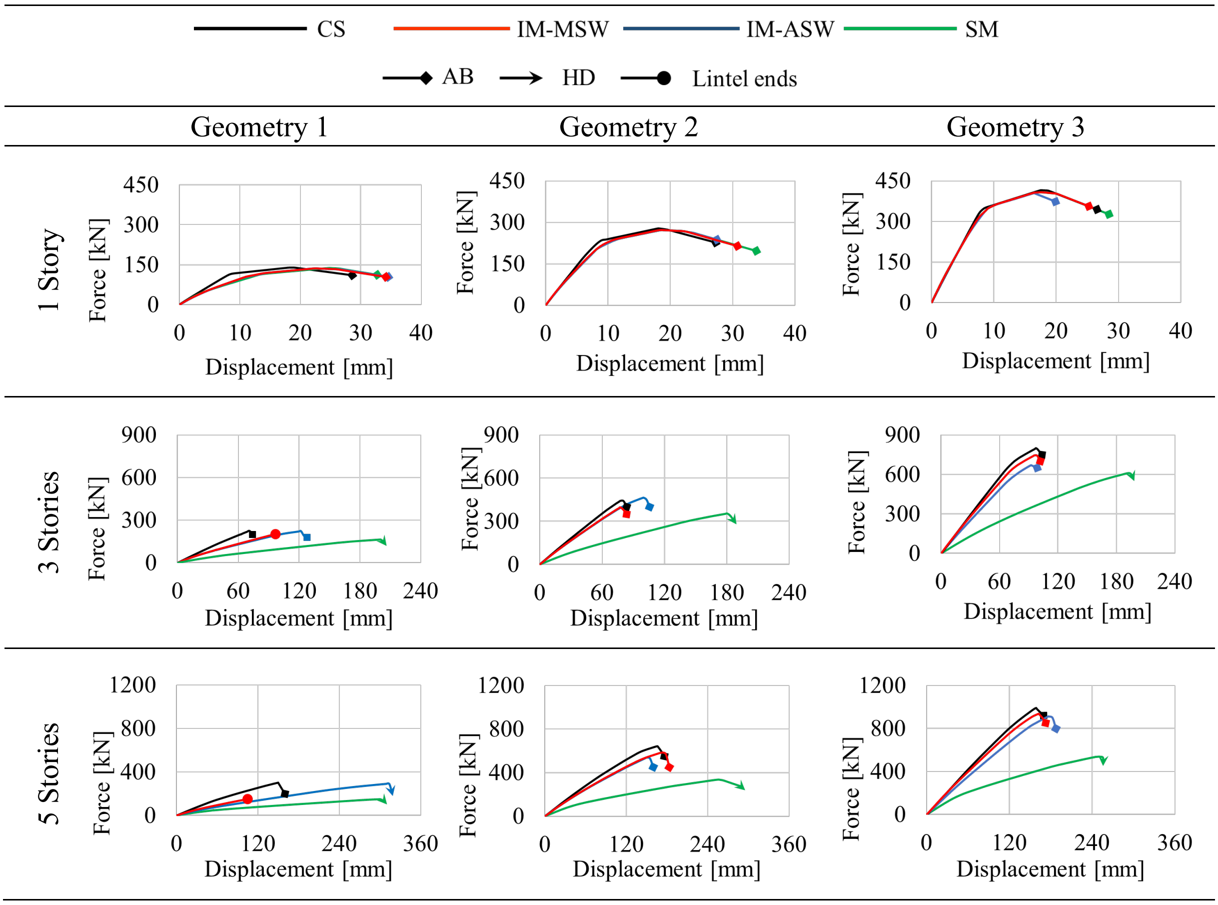


Figure 11: Pushover curves obtained from the nonlinear analyses.

In case of three-story systems, the results of the structures without openings (CS), show that sliding was the predominant deformation mechanism, resulting in shear failure of the angle brackets. On the other hand, for three-story CLT shear walls with openings modelled using the SM strategy, deformation was the consequence of a predominant rocking mechanism, resulting in tensile failure of the hold-downs. Whereas, in case of monolithic and assembled shear walls modelled with interactions (IM-MSW and IM-ASW, respectively), a combination of sliding and rocking deformation mechanisms occurred. In particular, these systems exhibit a predominant sliding mechanism; in fact, their lateral behavior is close to that of a system without openings (CS). Regarding the lateral performances, the maximum increments of the lateral capacity of the IM-MSW and IM-ASW strategies respect to the SM strategy are 22% and 35%, respectively, and occur for the cases with Geometry 1. On the other hand, the maximum decrements of the lateral capacity of the IM-MSW and IM-ASW strategies respect to the CS strategy are 10%, for Geometry 1, and 16%, for Geometry 3. This highlights that the lateral behavior of systems modeled with interactions is closer to that of systems without openings (CS) rather than that of systems modeled with the SM strategy.

Similar results were obtained in case of five-story systems, see Figure 11. Also in this case, multi-story shear walls modelled with interactions (IM-MSW and IM-ASW, respectively) deformed with a combination of sliding and rocking mechanism. Yet, in case of assembled shear walls (IM-ASW) with Geometry 1, a predominant rocking mechanism took place, which led to tensile failure of the hold-downs. Regarding the lateral performances of the five-story systems, the maximum increments of the lateral capacity of the IM-MSW and IM-ASW strategies respect to the SM strategy are equal to 75%, for the Geometry 3, and 93%, for the

Geometry 1. On the other hand, the maximum decrements of the lateral capacity of the IM-MSW and IM-ASW strategies respect to the CS strategy are equal to 51%, for the Geometry 1, and 16%, for the Geometry 2.

5 CONCLUSIONS

This study utilized numerical methods to examine the lateral behavior of multi-story Cross-Laminated Timber (CLT) shear walls. The study compared simplified modeling strategies (SM) to more advanced modeling strategies (IM) that account for structural interactions between lintels and wall segments, as well as between floors and wall segments. The study analyzed nine different structural configurations, including one-, three-, and five-story shear wall systems with three different geometries and varying mechanical properties at the base of the wall segments. The lateral performance of the advanced modeling strategies (IM-MSW and IM-ASW) for monolithic and assembled shear walls was compared to that of the simplified modeling strategy (SM) and a comparison system (CS) that modeled the same configurations of multi-story CLT shear walls without openings.

The results of the study showed that numerical models of monolithic and assembled shear walls, which take into account the structural interactions, resulted in significantly higher lateral stiffness and capacity values compared to the simplified modeling strategy (SM). In particular, these systems exhibit lateral performance close to the CS systems, which indicates that the structural interactions provided a significant contribution to the lateral performance of the multi-story CLT shear walls, due to the bending contribution of lintels and floors.

The study also suggested that the simplified modeling strategies often used for the design of CLT structures may not always properly describe the behavior of a multi-story CLT building subjected to horizontal loads. Therefore, the use of advanced modeling strategies that account for structural interactions should be considered when designing multi-story CLT shear walls to accurately predict their lateral behavior.

This study highlights the importance of considering the lateral behavior of multi-story CLT shear walls in the design of CLT structures. By using advanced modeling strategies that account for structural interactions, it is possible to accurately predict the lateral behavior of multi-story CLT shear walls and ensure the safety and stability of the building lateral loads.

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