FORUM HOLZBAU INTERNATIONAL

30. November - 2. Dezember 2022

Aalto University School of Engineering

SWECO

Lukas Kotrbaty

Lateral Load Transfer in Multi-story Timber Modular Buildings

01/12/2022

- Info
- Background & motivation
- 2D FEM
- Reference building
- Parameter study
- Conclusion
- Questions & Feedback

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General info

#MasterThesis2020

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Advisor: **Gerhard Fink**, Aalto University

Supervisor: **Lauri Lepikonmäki**, Sweco Structural Engineering, Tampere

February 2020 → July 2020

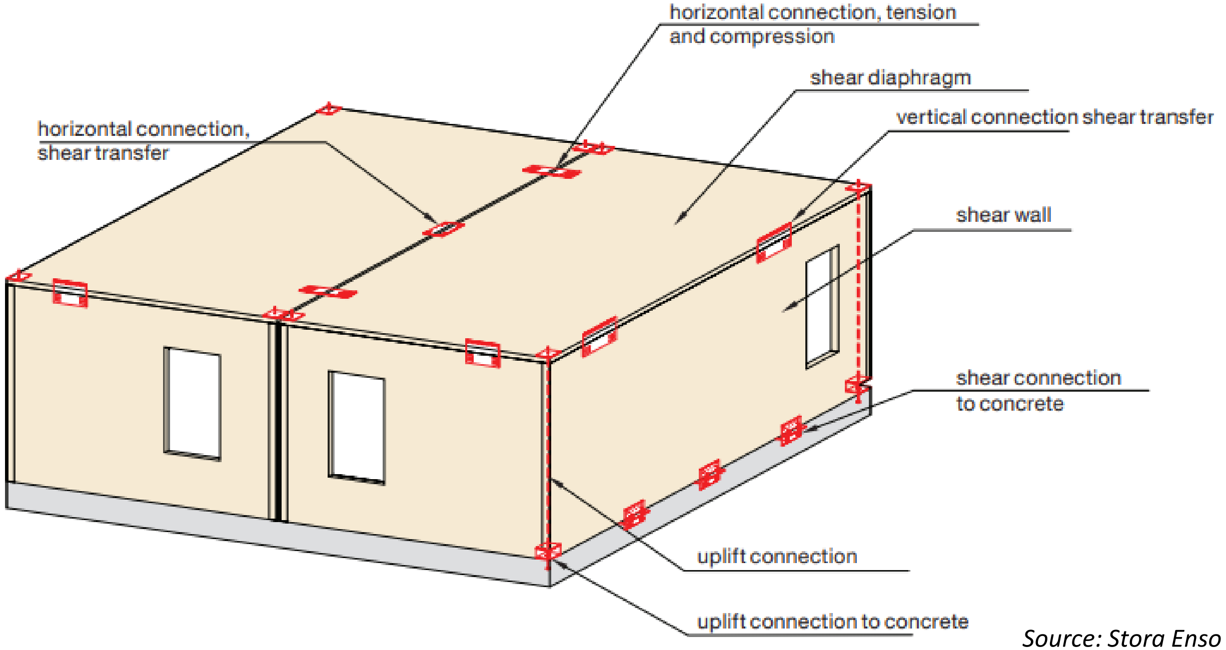
Background

#MultistoryTimberModularBuildings #Stability #LateralLoadTransfer #IntermediateFloor #ShearWalls

Volumetric modules construction

Source: WAUGH THISTLETON ARCHITECTS

Modules connected together



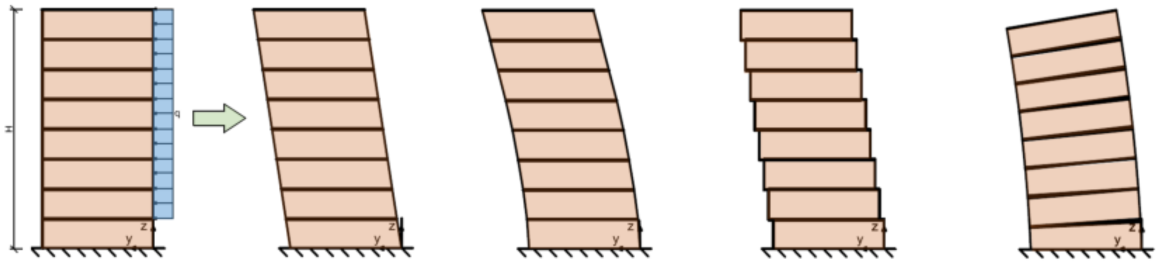
Source: Stora Enso

Background

#MultistoryTimberModularBuildings #Stability #LateralLoadTransfer #IntermediateFloor #ShearWalls

Lateral stability of the building

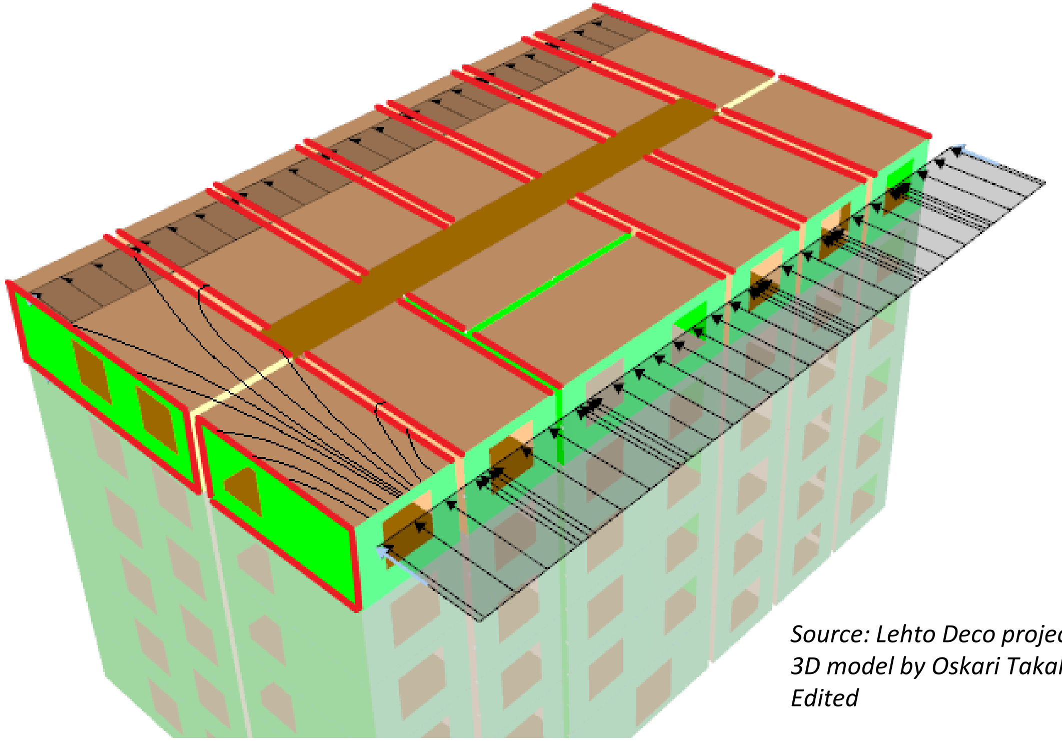
- wind load safely transferred from facade to foundations



Source: Jussi Junttila, Master thesis

Lateral load distribution

- Intermediate floor -->> Shear walls



Source: Lehto Deco project
3D model by Oskari Takala
Edited

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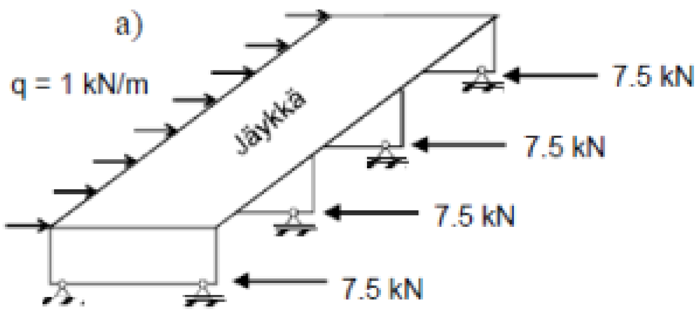
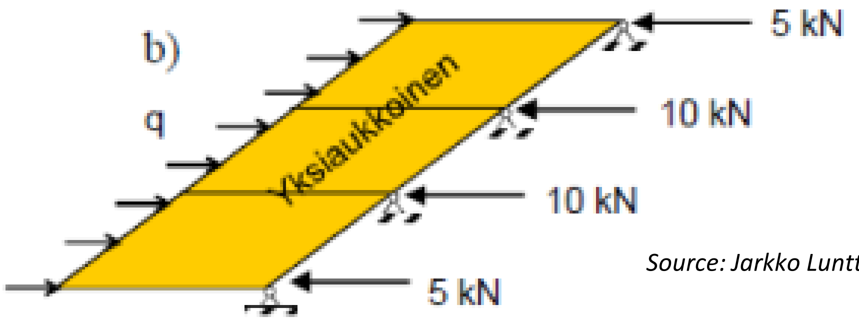
Motivation

#LateralLoadDistribution   #IntermediateFloor-->>ShearWalls

Different ways of modelling the intermediate floor in order to get load distribution in preliminary stage of projects





Source: Jarkko Luntta, Master thesis

Rigid intermediate floor
-Distribution dependent on stiffness of shear walls

Flexible intermediate floor
-Distribution dependent on tributary areas

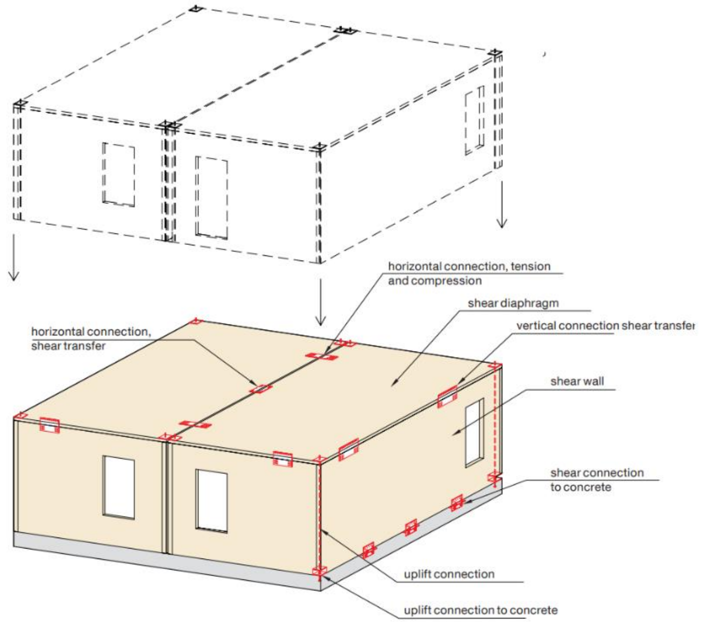
In reality, intermediate floor is **semi-rigid**.

What are the factors, which influence the lateral load distribution,
and how they could be taken into account in preliminary stage of projects?

Solution

#2DFEM

Input data	Flexible floor	Rigid floor	2D FEM	3D FEM
Geometry of intermediate floor	✓	✓	✓	✓
Positions of shear walls	✓	✓	✓	✓
Wind load [kN/m]	✓	✓	✓	✓
Stiffness of shear walls	✗	✓	✓	✓
Stiffness of room modules in intermediate floor (orthotropic properties included)	✗	✗	✓	✓
Stiffness of corridor in intermediate floor (orthotropic properties included)	✗	✗	✓	✓
Stiffness of inter-module connections (within intermediate floor)	✗	✗	✓	✓
Stiffness of module-corridor connections (within intermediate floor)	✗	✗	✓	✓
Stiffness of intra-module connections between floor and walls	✗	✗	✓	✓
Bending moment deflection of the building	✗	✗	✓	✓
Stiffness of vibration insulation (rubber)	✗	✗	✓	✓
Stiffness of uplift connections	✗	✗	✗	✓
Friction connection wood - rubber	✗	✗	✗	✓

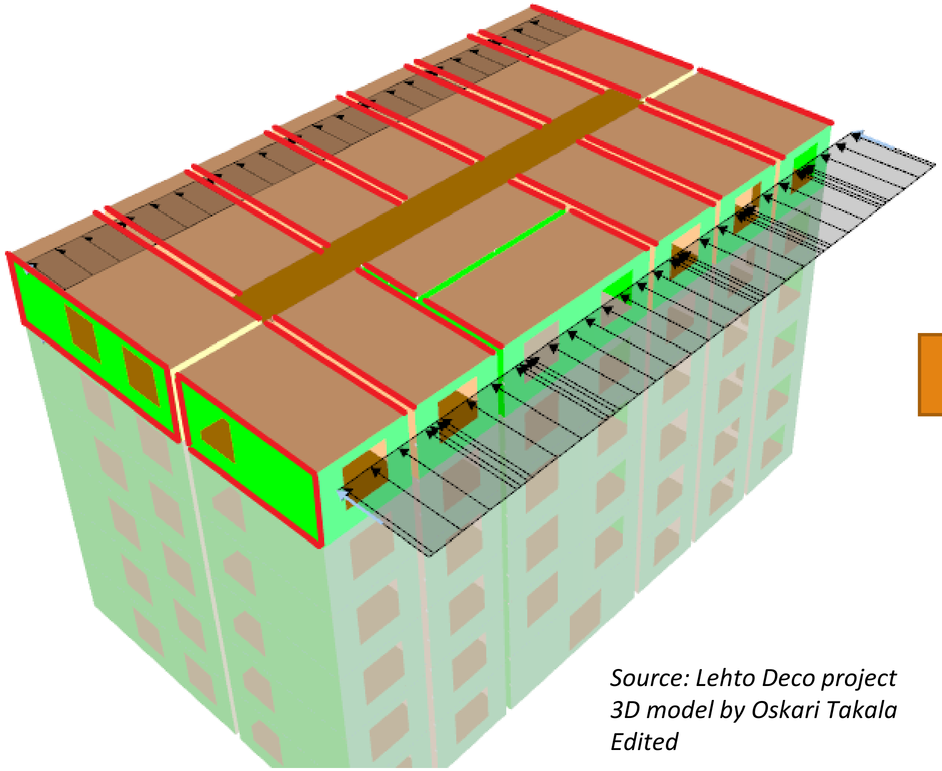


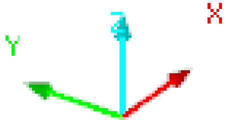
2D FEM can take more factors into account - stiffness of intermediate floor, stiffness of connections,…

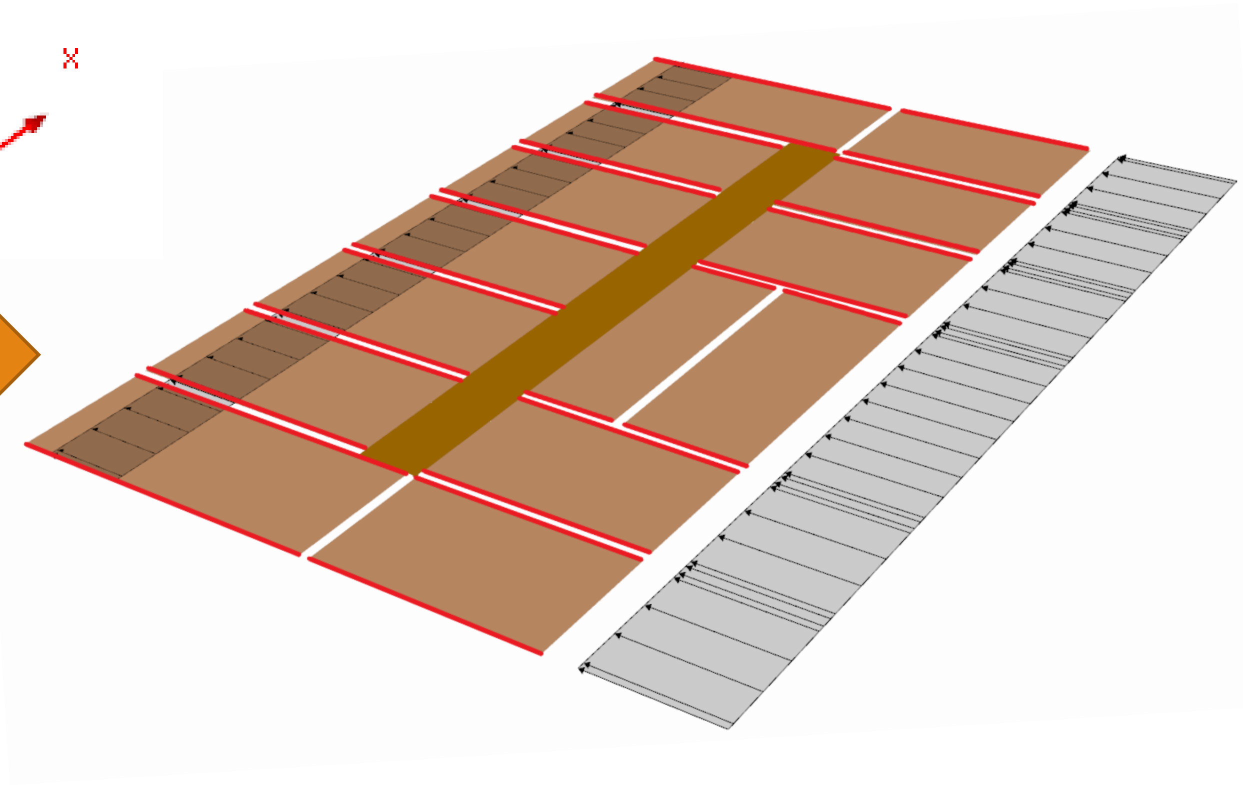
Faster and simplier than 3D FEM model

2D FEM

#2DFEM #Model



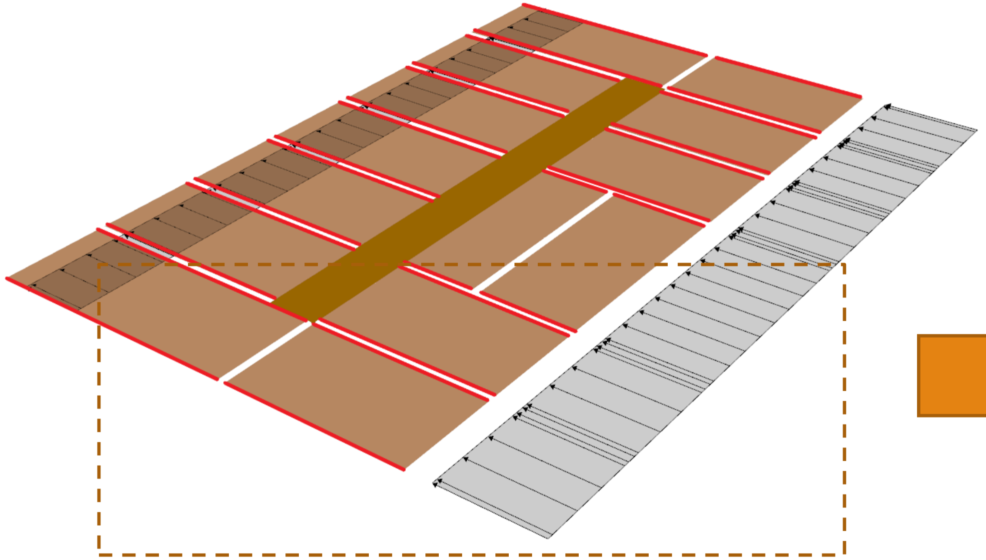


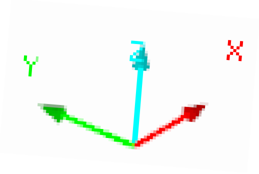


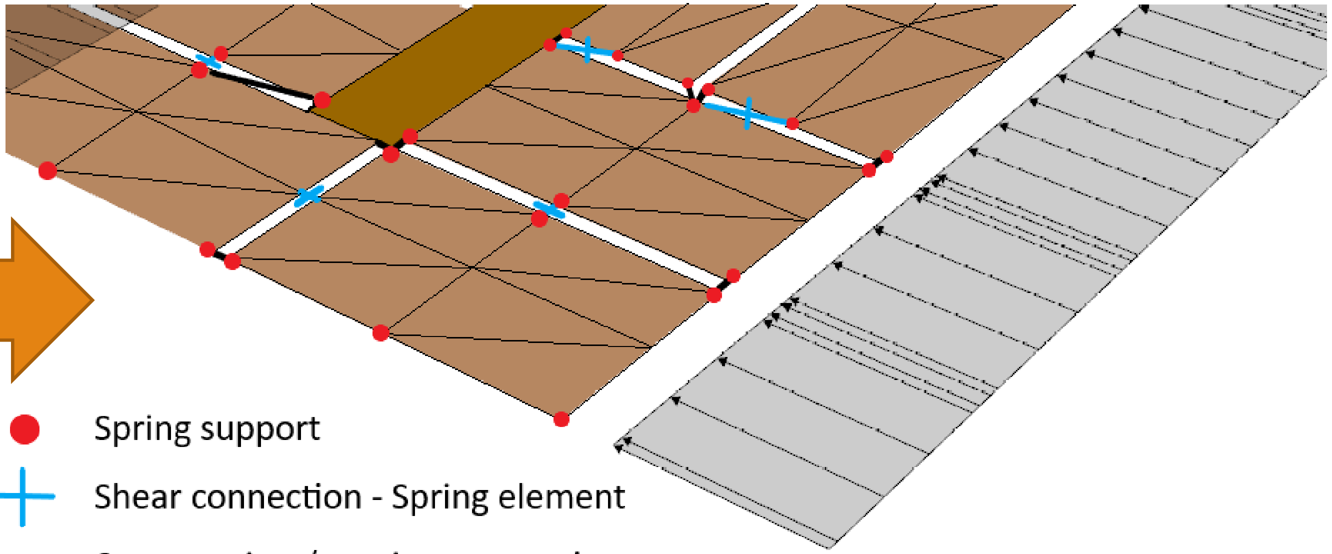
Source: Lehto Deco project
3D model by Oskari Takala
Edited

2D FEM

#2DFEM #Model



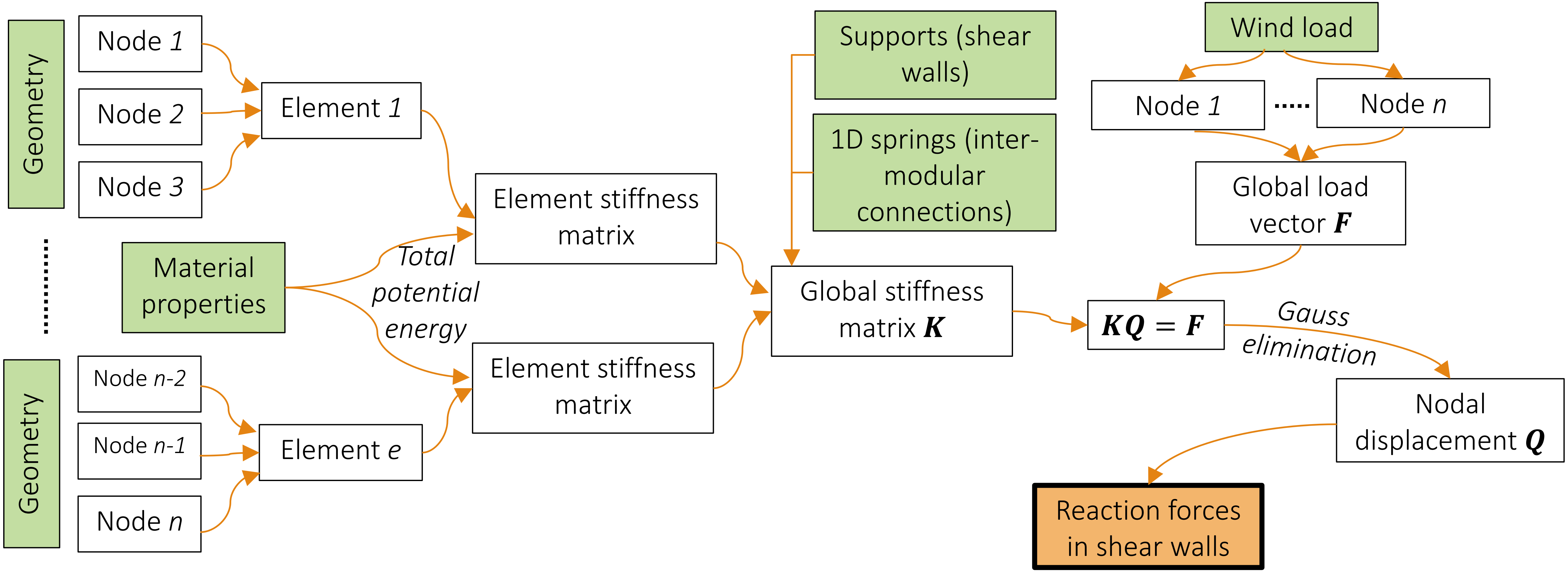




- Spring support
- Shear connection - Spring element
- Compression / tension connection - Spring element

2D FEM

#2DFEM #Characteristics #System



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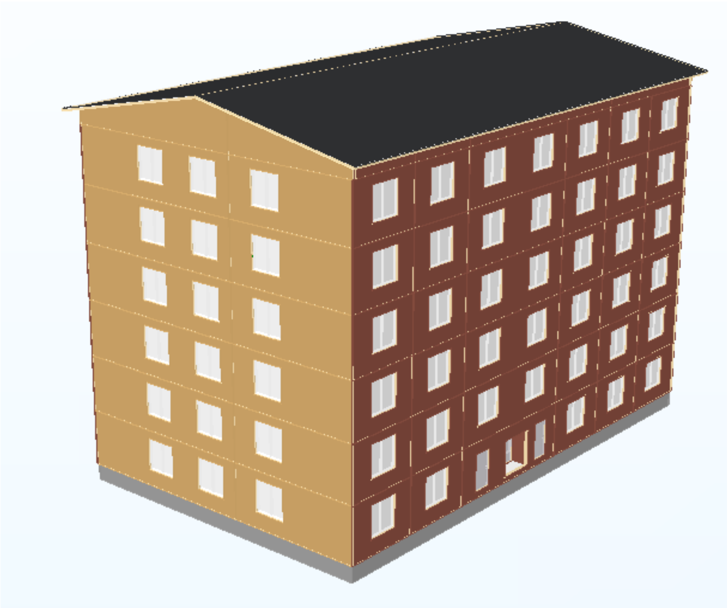
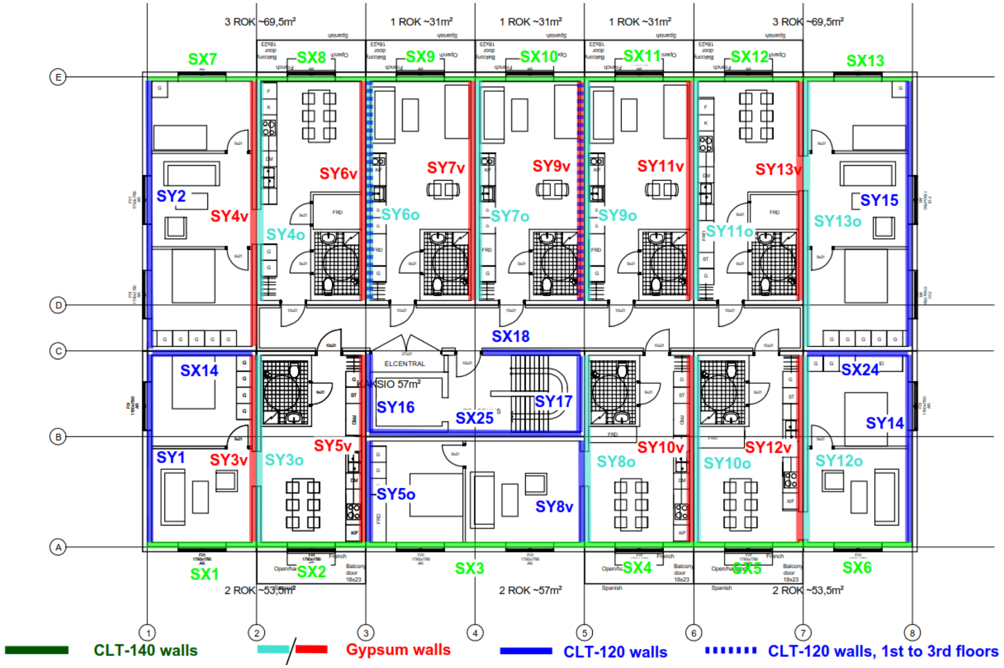
2D x 3D - Reference project

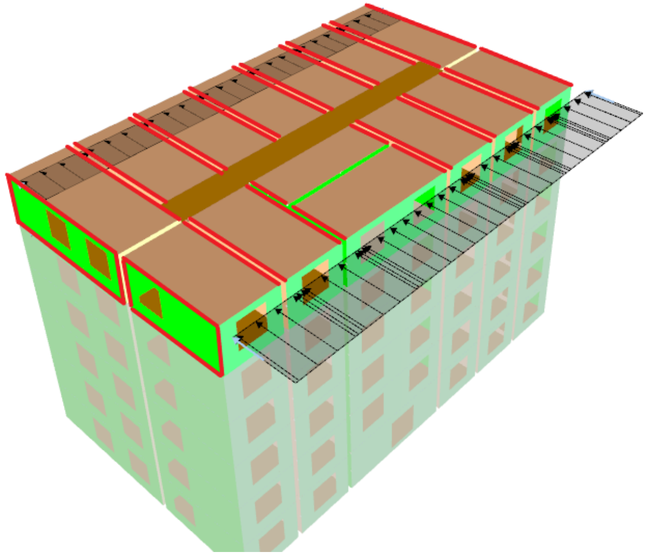
#Timber #ModularConstruction #SixStories

- Concept of six-story timber modular apartment building
- Walls: CLT or stud walls (timber frame + gypsum)
- Floors: LVL beams + OSB sheathing



Source: Sweco structural model, Lehto Deco concept

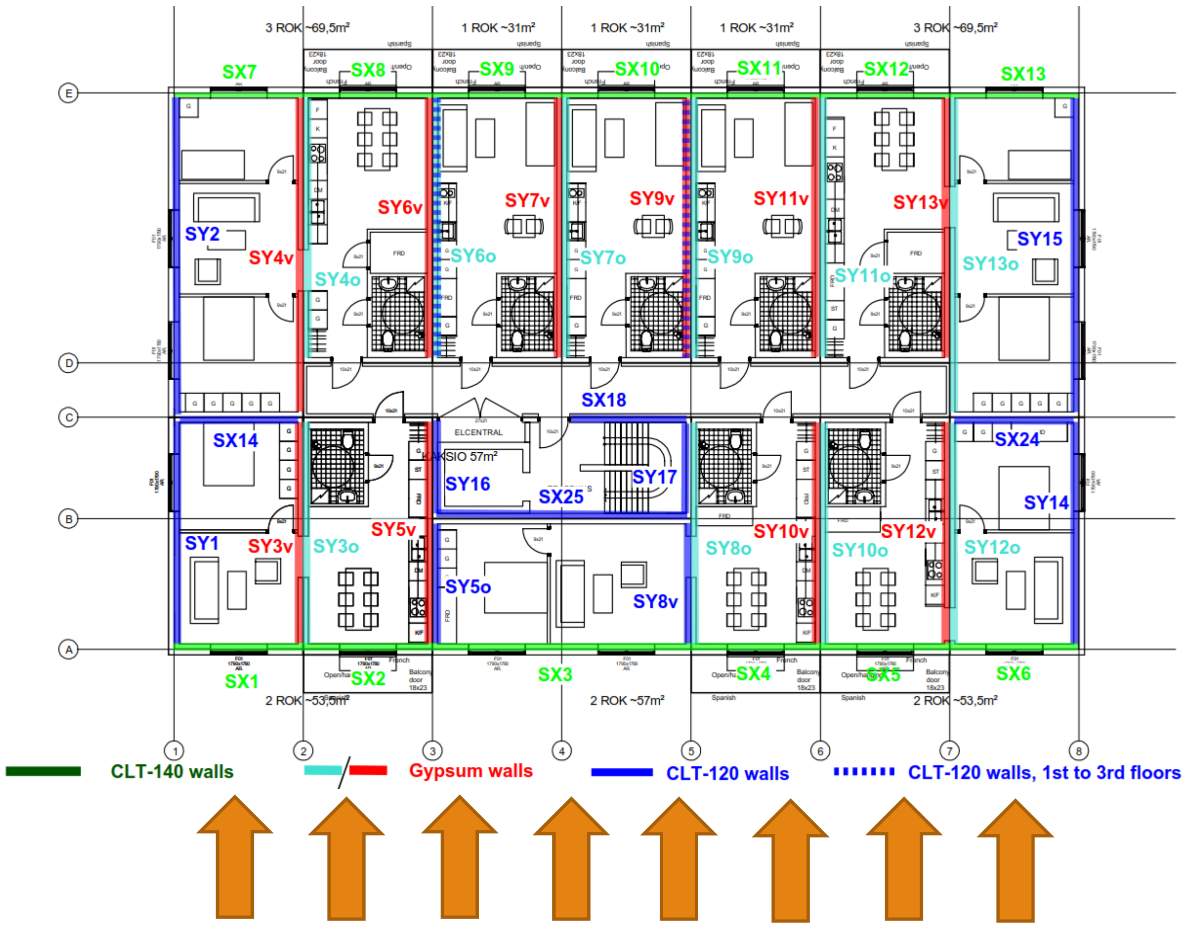




Source: Lehto Deco project 3D model by Oskari Takala, Edited

2D x 3D - Results

#Results #2DFEM #Validation #Comparison #3DFEM #ShearForces

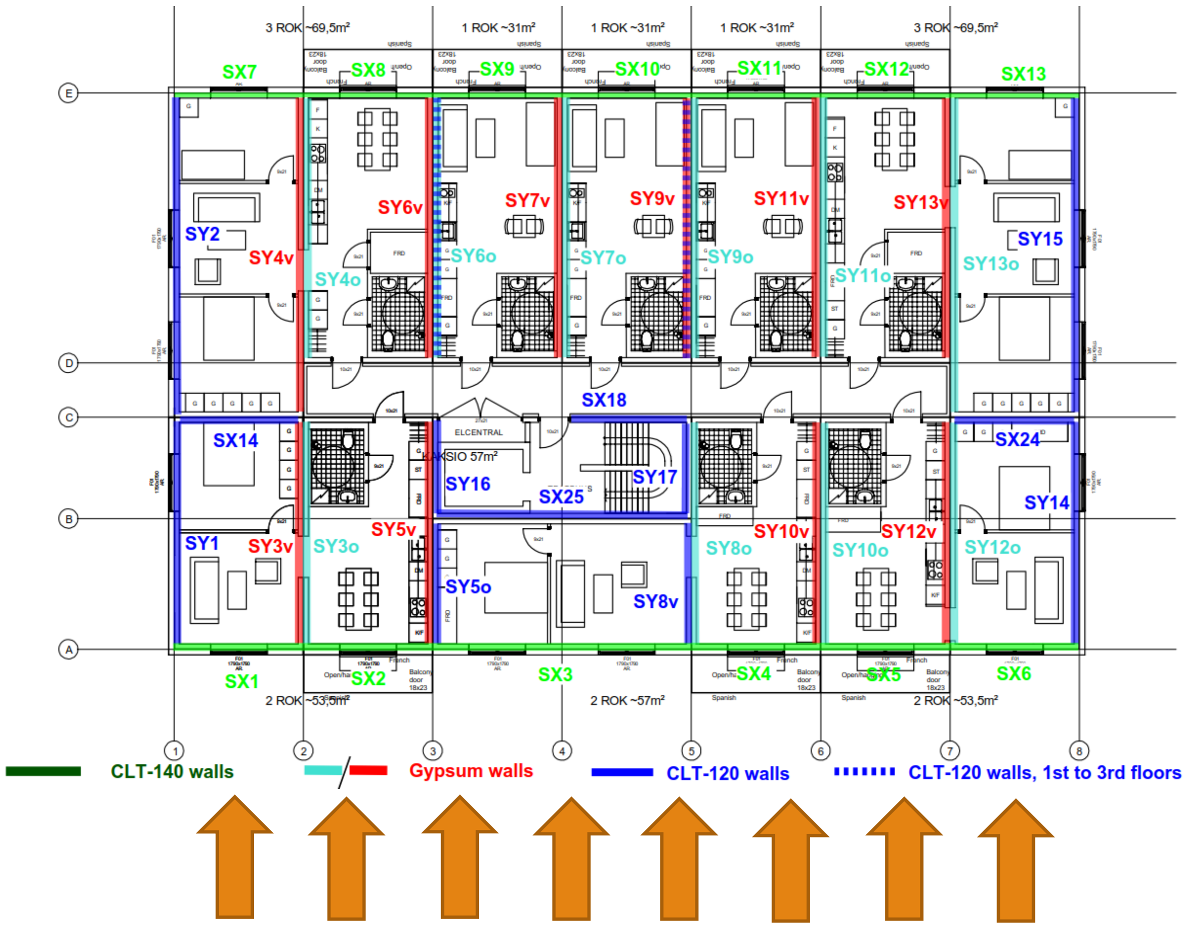


Y	3D FEM [%]						2D FEM [%]					
	floor						floor					
	1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th	6th
SY1	7	7	7	7	7	7	6	6	6	6	6	6
SY2	8	9	9	10	10	11	7	8	8	9	9	9
SY3v	1	1	1	1	1	1	2	1	1	1	1	1
SY3o	1	1	1	0	0	-2	2	2	1	1	1	1
SY4v	2	2	3	3	4	4	3	2	2	3	3	3
SY4o	2	2	2	2	3	3	2	2	2	2	2	2
SY5v	1	2	2	2	2	1	2	2	2	2	2	2
SY5o	6	5	4	3	3	3	6	6	6	5	5	5
SY6v	2	2	3	4	4	4	2	2	2	2	2	2
SY6o	9	8	8	6	4	4	7	8	8	8	8	7
SY7v	2	2	3	4	5	6	2	2	2	2	2	3
SY7o	2	2	3	4	4	5	2	2	2	2	2	3
SY8v	5	4	4	3	3	3	5	5	4	4	3	3
SY8o	2	2	1	1	1	0	2	2	2	2	2	2
SY9v	9	9	9	8	6	6	8	8	9	9	8	8
SY9o	3	3	3	3	3	4	2	2	2	2	3	3
SY10v	2	2	2	2	2	1	3	3	3	3	3	2
SY10o	2	2	2	2	1	1	3	3	3	3	3	2
SY11v	3	3	3	3	4	5	3	3	3	3	3	3
SY11o	3	3	3	3	3	3	3	3	3	3	3	3
SY12v	2	2	2	1	1	0	2	2	2	2	1	1
SY12o	2	2	2	2	2	2	2	2	2	1	1	1
SY13v	2	2	2	2	2	2	2	2	2	2	2	2
SY13o	2	3	3	3	3	4	3	3	3	3	3	3
SY14	8	7	7	7	7	8	6	6	6	6	7	7
SY15	8	9	9	10	10	11	8	9	9	9	10	10
SY16	3	2	2	1	1	0	3	3	3	3	2	2
SY17	2	2	2	3	4	3	4	4	3	3	3	3
SUM	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Scale [%]
11
10
9
8
7
6
5
4
3
2
1
0

2D x other simplified methods

#Results #2DFEM #Validation #Comparison #3DFEM #ShearForces



Δ [pp] = given method [%] - 3D FEM [%]

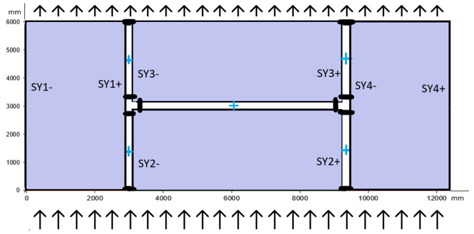
Y	2D FEM [pp]						Tributary areas [pp]						Rigid floor [pp]					
	floor						floor						floor					
	1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th	6th
SY1	-1	-1	-1	-1	-1	-1	-4	-4	-4	-4	-4	-4	2	2	2	2	1	1
SY2	-1	-1	-1	-1	-1	-1	-4	-5	-5	-6	-6	-7	2	2	1	1	0	0
SY3v	0	0	0	0	0	0	2	1	1	1	2	1	-1	-1	-1	-1	-1	-1
SY3o	0	1	1	1	1	3	2	2	2	3	3	5	-1	-1	0	0	0	2
SY4v	1	0	0	-1	-1	-2	2	2	2	1	1	0	-1	-2	-2	-3	-3	-4
SY4o	0	0	0	-1	-1	-1	2	2	2	2	1	1	-1	-1	-2	-2	-2	-3
SY5v	1	0	0	0	0	1	2	1	1	1	2	2	-1	-2	-2	-2	-1	-1
SY5o	0	1	2	2	2	2	1	2	2	2	3	3	1	2	3	3	3	4
SY6v	0	0	-1	-2	-2	-2	2	2	1	0	0	-1	-1	-2	-2	-4	-4	-4
SY6o	-2	-1	0	2	3	3	-7	-6	-5	-2	0	0	5	6	6	8	10	10
SY7v	0	0	0	-1	-2	-3	-1	-2	-2	-3	-5	-5	-1	-2	-2	-3	-4	-5
SY7o	0	0	0	-1	-2	-2	-1	-2	-2	-3	-4	-5	-1	-2	-2	-3	-4	-4
SY8v	0	1	1	0	0	0	2	3	3	2	3	3	0	1	1	1	2	2
SY8o	0	0	1	1	1	2	1	1	2	2	2	3	-2	-1	-1	0	0	1
SY9v	-1	-1	-1	1	3	2	-6	-6	-6	-4	-2	-2	6	6	6	7	9	9
SY9o	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	-2	-2	-2	-3	-3	-3
SY10v	0	1	1	1	1	1	1	1	1	1	1	2	-2	-2	-2	-2	-2	-1
SY10o	0	1	1	1	1	1	1	1	1	2	2	2	-2	-2	-1	-1	-1	-1
SY11v	0	0	0	-1	-1	-2	1	1	1	0	0	-1	-2	-2	-3	-3	-3	-4
SY11o	0	0	0	0	0	0	1	1	1	1	1	1	-2	-2	-2	-2	-3	-3
SY12v	0	0	0	0	1	2	1	1	2	2	3	3	-2	-1	-1	-1	0	0
SY12o	0	0	0	0	0	-1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-2
SY13v	0	0	0	0	0	0	2	2	2	2	2	2	-2	-1	-1	-1	-1	-1
SY13o	1	0	0	0	-1	-1	2	2	1	1	1	1	-2	-2	-2	-3	-3	-3
SY14	-2	-1	-1	-1	-1	-1	-4	-4	-4	-4	-4	-4	3	3	3	3	3	3
SY15	0	0	0	0	0	-1	-5	-5	-5	-6	-6	-7	4	4	3	3	2	2
SY16	1	1	1	1	1	2	2	3	3	3	3	4	2	3	3	4	4	5
SY17	2	1	1	0	-1	0	3	2	2	2	1	1	3	3	3	3	2	2

Scale [pp]
10
8
6
4
2
0
-2
-4
-6
-8
-10

Parameter study

#Analysis #LoadDistribution #Factors

- Simple layouts, only few modules
- Properties same as in reference project, only the one under investigation changing
- Differences in intermediate floor
  - Tension / compression connection
  - Stiffness of intermediate floor
- Differences in shear walls
  - Whole stiffness of shear wall
  - Bending deflection of shear walls -> multi-story effect
- Diffecences in layouts
  - Which layout gives more equal distribution?



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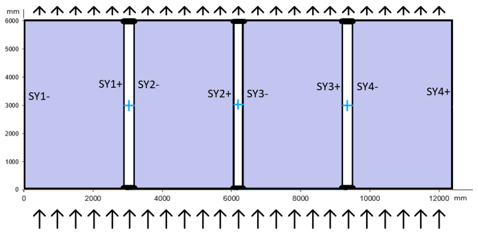
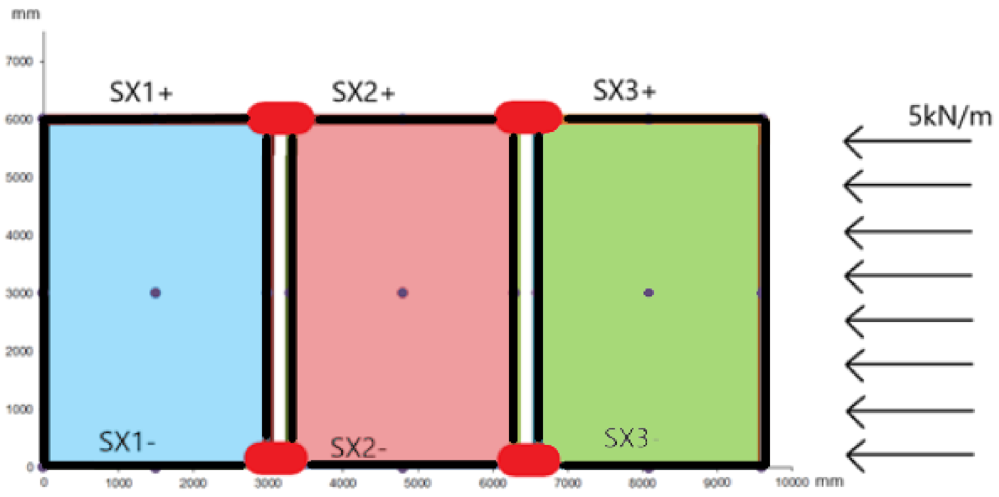
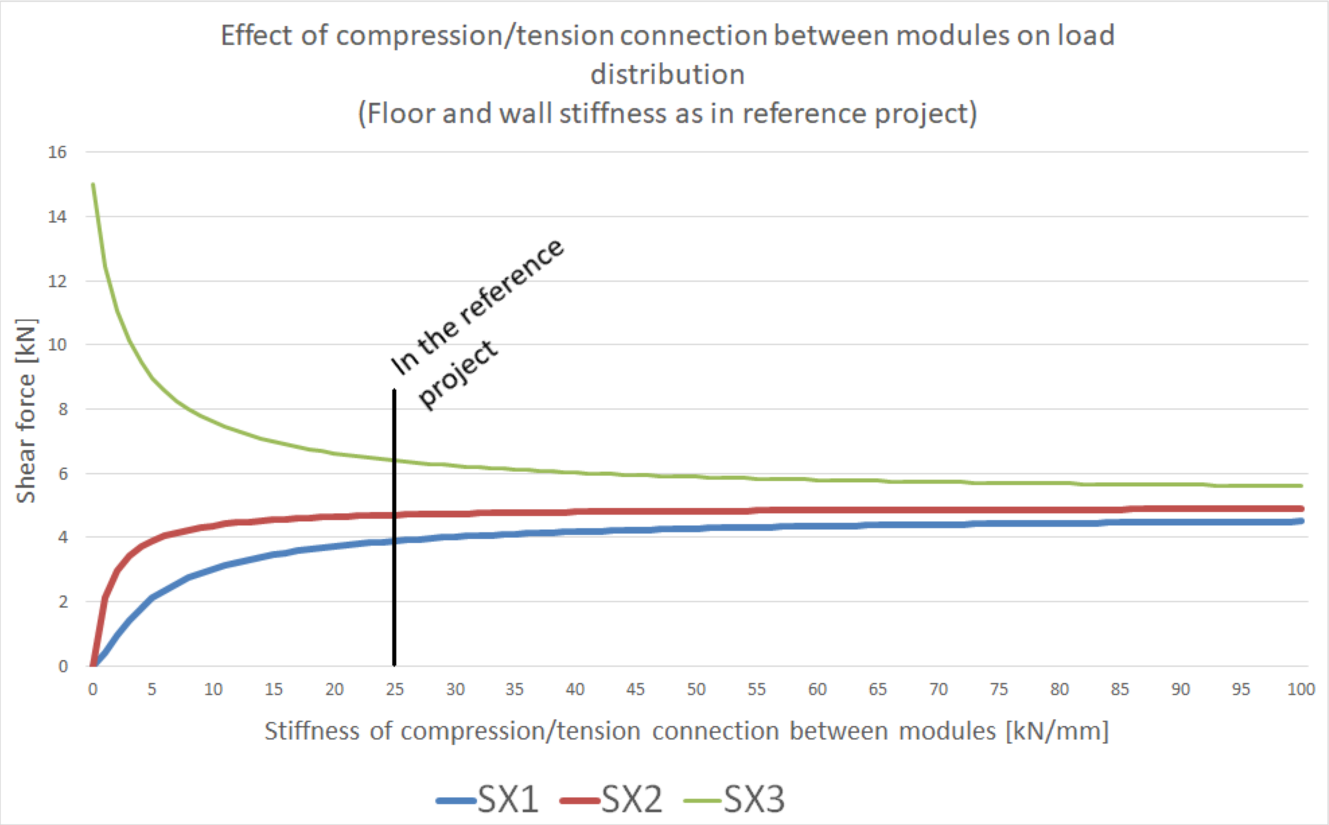


Tension / Compression connection

#Analysis #Results #Factors #InterConnections #FloorLevel

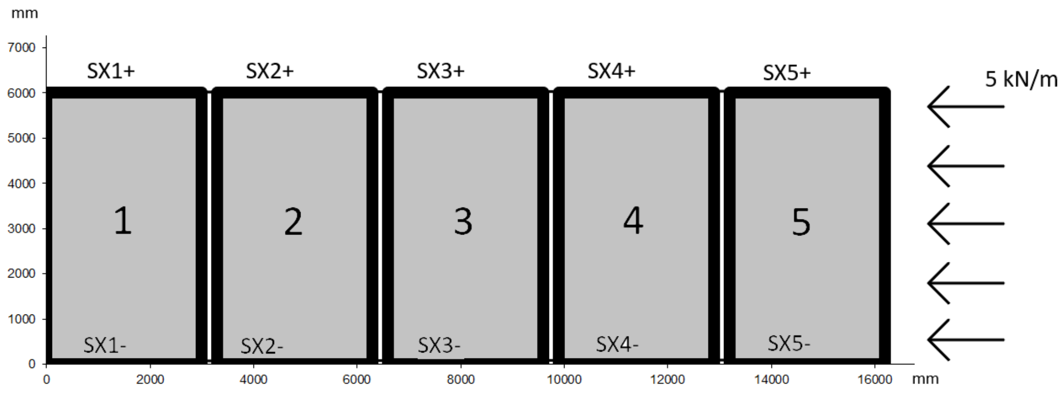




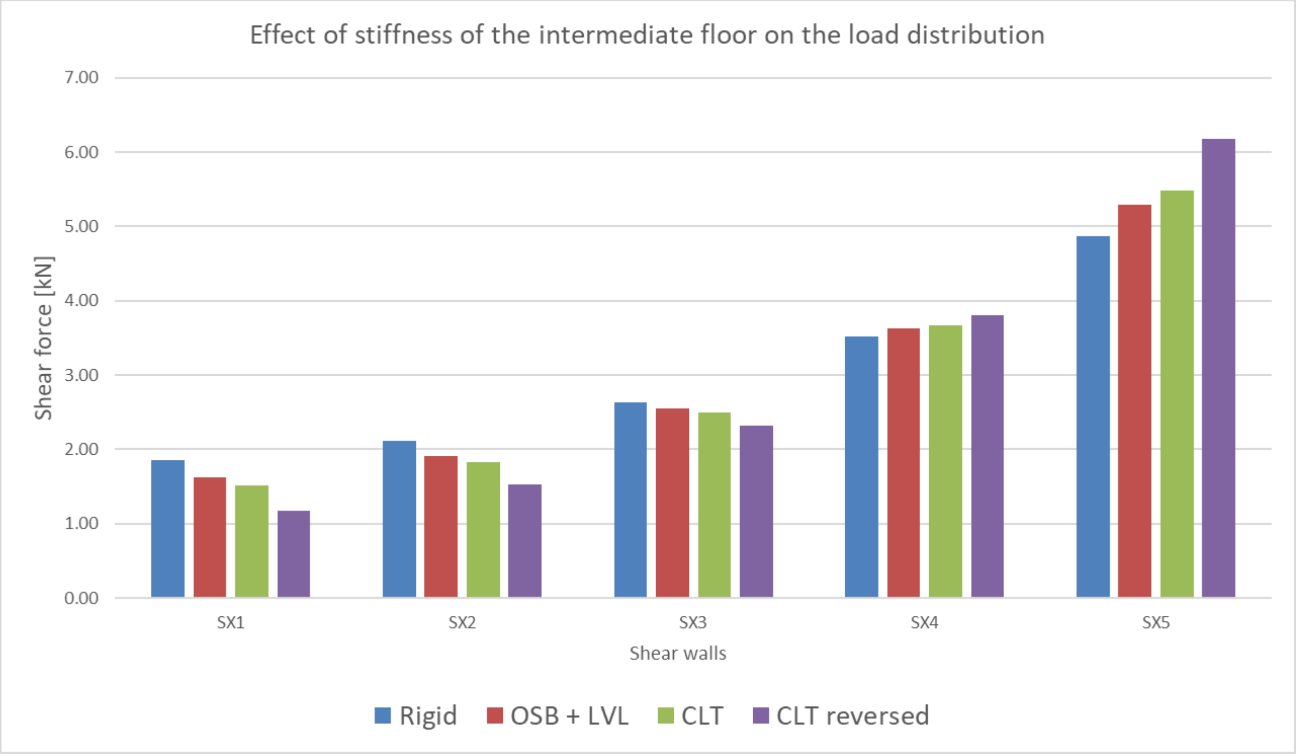
- All three modules same stiffness properties (as in reference project – LVL beams with OSB sheathing)

Stiffness of intermediate floor

#Analysis #Results #Factors #Stiffness #IntermediateFloor #DifferentMaterials

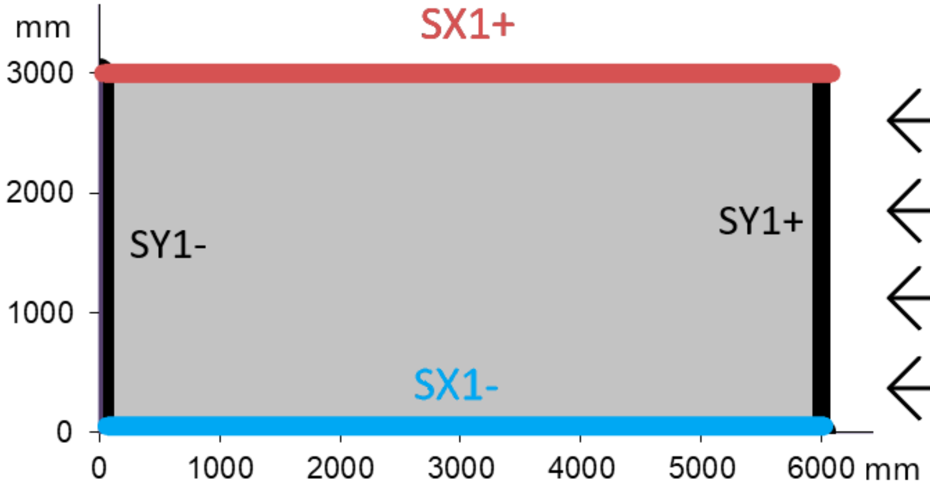


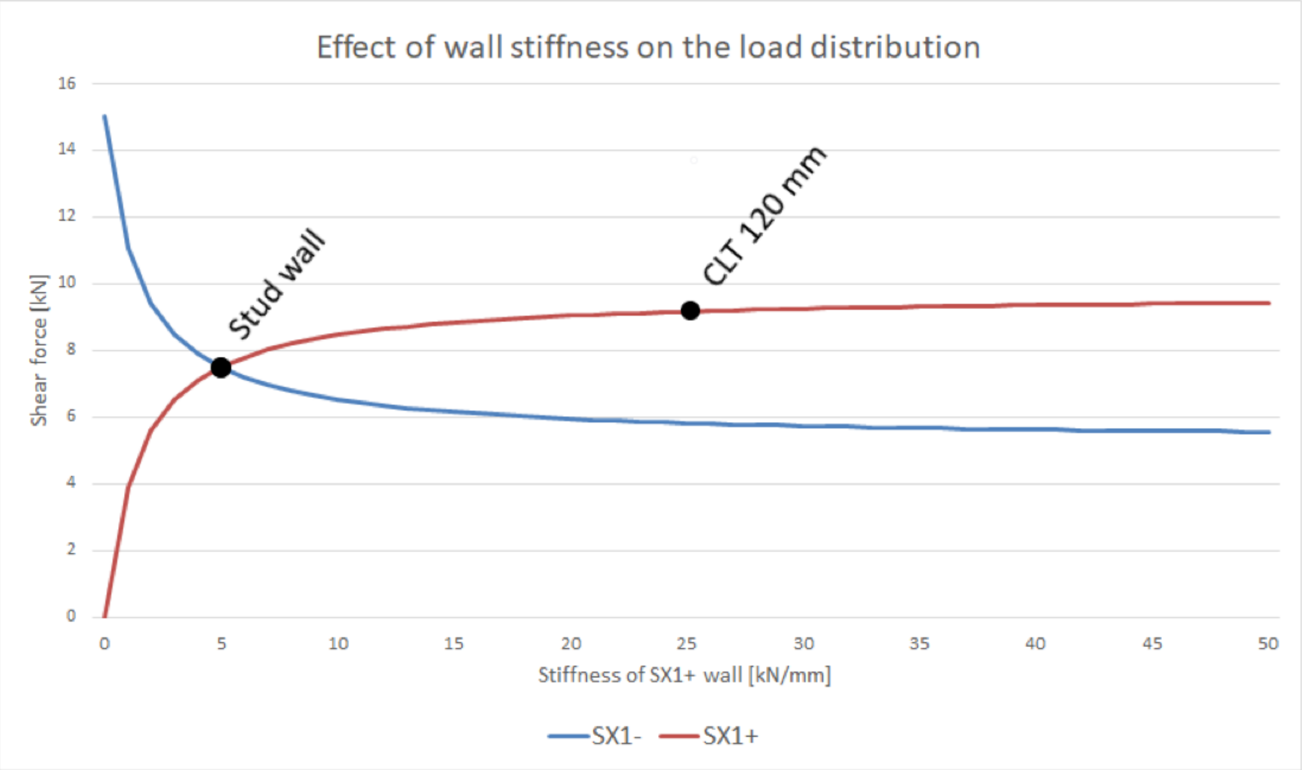
Material properties table (d = 15 mm)						
Name	E_X [GPa]	E_Y[GPa]	G_XY [GPa]	nu_XY	OR	nu_YX
rigid	100000.00	100000.00	100000.00	0.00	x	
LVL beams + OSB sheathing	12.20	24.40	0.12	0.00	x	
CLT 140 mm	7.86	3.14	0.69	0.00	x	
CLT 140 mm reversed	3.14	7.86	0.69	0.00	x	



Stiffness of shear walls

#Analysis #Results #Factors #Stiffness #ShearWalls





- SY1-, SY1+ constant stiffness 2.5 kN/mm
- SX1, constant stiffness **5 kN/mm**
- SX1+ variable stiffness (horiz. axis in chart)
- Floor as in the reference project (LVL + OSB)
- In this case, load not distributed in a ratio of wall stifnesses

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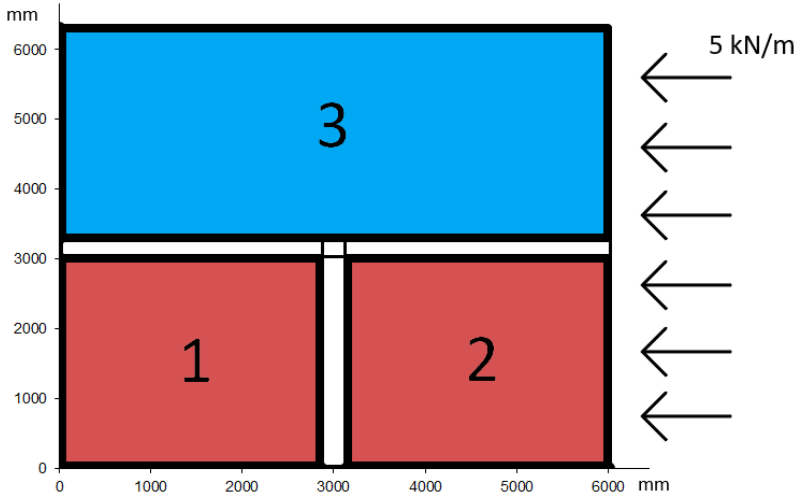
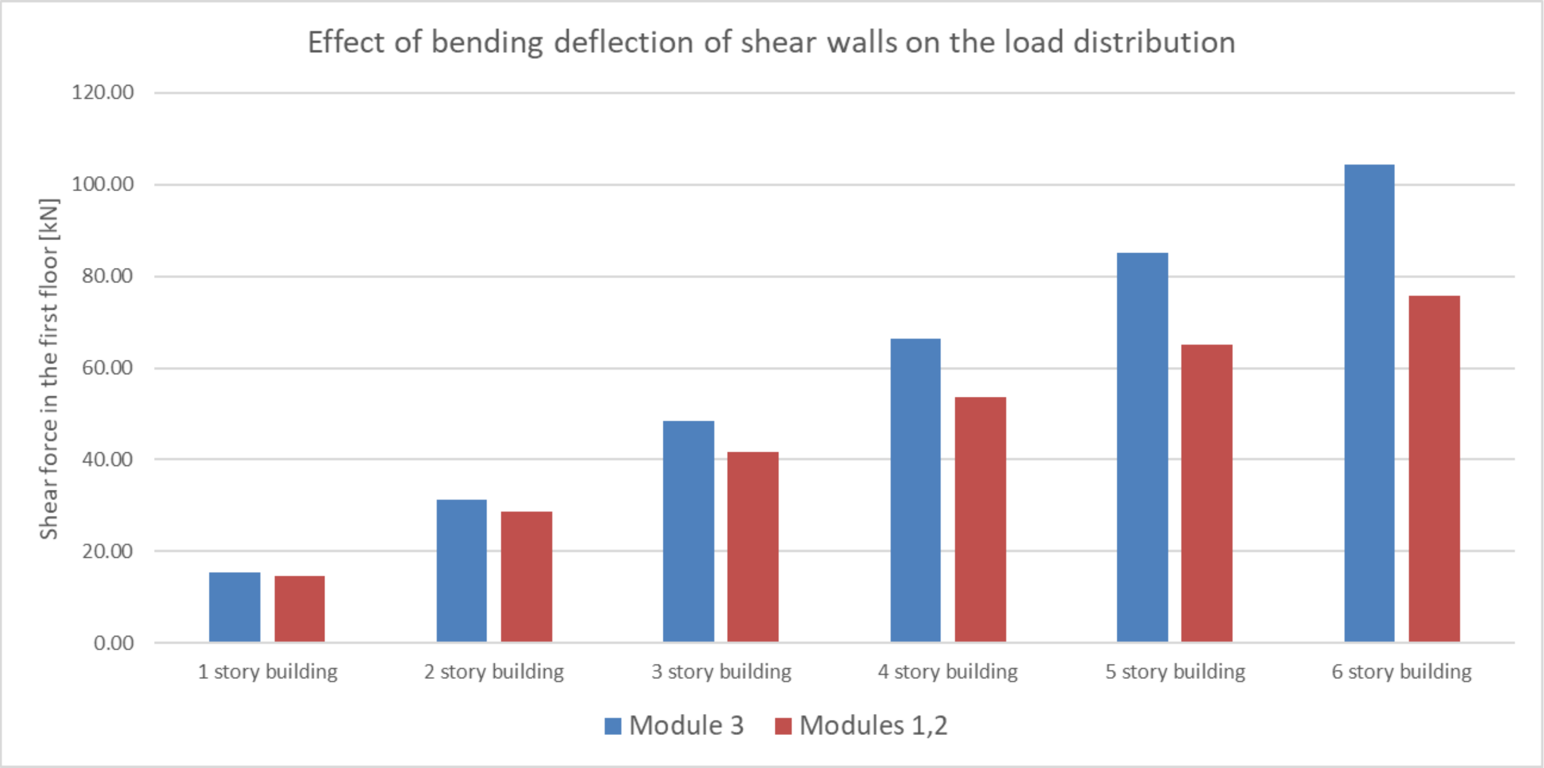
Bending deflection of shear walls

#Analysis #Results #Factors #BendingDeflection #ShearWalls

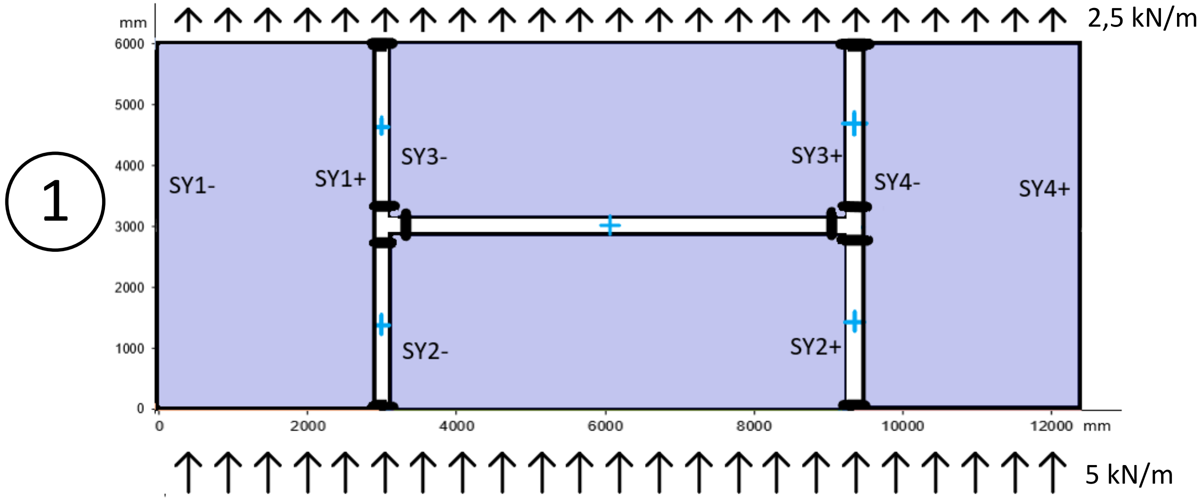




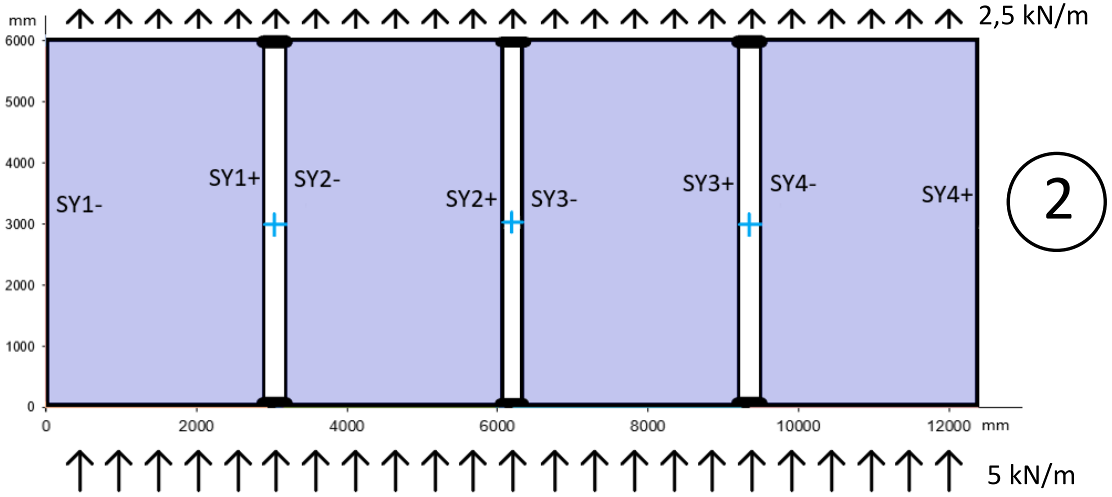
- All shear walls – same material (CLT 120 mm)
- Floors as in reference project (LVL + OSB)

Layouts

#Analysis #Results #Factors #Layouts #ShearWallsPosition



OR



1 floor building

	Shear force [kN]	Load distribution [%]
SY1-	11.1	13%
SY1+	**15.7**	**18%**
SY2+	9.3	11%
SY2-	9.3	11%
SY3-	7.8	9%
SY3+	7.8	9%
SY4-	**15.7**	**18%**
SY4+	11.1	13%
SUM	87.7	100%

6 floors building

	Shear force in 1st floor [kN]	Load distribution [%]
SY1-	79.8	15%
SY1+	**108.6**	**21%**
SY2+	38.9	7%
SY2-	39.0	7%
SY3-	35.9	7%
SY3+	36.0	7%
SY4-	**108.8**	**21%**
SY4+	79.6	15%
SUM	526.5	100%

1 floor building

	Shear force [kN]	Load distribution [%]
SY1-	11.0	12.5%
SY1+	11.0	12.5%
SY2+	11.0	12.5%
SY2-	11.0	12.5%
SY3-	11.0	12.5%
SY3+	11.0	12.5%
SY4-	11.0	12.5%
SY4+	11.0	12.5%
SUM	87.7	100%

6 floors building

	Shear force in 1st floor [kN]	Load distribution [%]
SY1-	65.8	12.5%
SY1+	65.8	12.5%
SY2+	65.8	12.5%
SY2-	65.8	12.5%
SY3-	65.8	12.5%
SY3+	65.8	12.5%
SY4-	65.8	12.5%
SY4+	65.8	12.5%
SUM	526.3	100%

To sum it up…

#Conclusion #WhatHasBeenDone

- Analysis of lateral load distribution from intermediate floor to shear walls in multi-storey timber modular buildings carried out
  - 2D FEM introduced
  - 2D FEM used in a reference project and compared with commonly used methods
  - (Some of the) Factors playing a role in the load transfer separately investigated

To sum it up…

#Conclusion #Results #FutureConsiderations

- Presented 2D FEM is applicable for load distribution analysis in multi-story timber modular buildings, however, not all parameters can be considered as they are in 3D models

- It has been shown how stiffness of shear walls, stiffness of intermediate floor, and stiffness of connections affect the load distribution
  - The stiffness of both the connections between modules and the intermediate floor affects the load distribution and should not be neglected
  - Load does not need to be transffered to the shear walls according to the ratio of their stiffnesses
  - Load distribution changes in each floor mainly due to bending deflection of walls

- Presented 2D FEM could be used for optimalization of multi-story timber modular buildings

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SWECO

Questions & Feedback

#AskMe

Thank you for listening!

Questions?

Any comments appreciated !

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