JOINT DESIGN FOR INDEPENDENT SHEARING LATERS TO ACHIEVE AN ADAPTABLE TIMBER BUILDING

Yanzhen Wu

Faculty of Architecture & the Built Environment, Delft University of Technology

Julianalaan 134, 2628BL Delft

ABSTRACT

The paper aims to evaluate the adaptability of multi-storey timber buildings by analysing the independence of shearing layers, mainly focusing on the joint design between building elements. The paper compared two cases, the Library and Seminar Centre (Case 1) and Pile up Giesshübel (Case 2), to figure out how joint design affects the adaptability under the scene of altering the function using the Dependency Structure Matrix model. The clustering analysis studied the dependencies between the building elements and classified elements into shearing layers. It found that Case 1 has fewer dependencies between elements and can be better decomposed into independent layers than Case 2. The impact analysis studied the propagation impact of chosen elements in the space plan, skin and services layers. It proved that Case 1 is much more adaptable than the other case when changing the space plan and services due to its relevantly detached joint design in critical positions. Besides, the two cases both show good adaptability when changing the skin. The paper provides a methodology, based on Brand's 'shearing layers' model, to verify an existing building's adaptability or assist in designing a new adaptable building.

KEYWORDS: *Adaptable timber building, Shearing Layers, Joint design, Details*

I. INTRODUCTION

As climate change and resource scarcities become urgent worldwide, there has been an increasing focus on strategies and techniques that help achieve a more sustainable future. On the one hand, the concept of adaptability has gradually come into people's vision. During a building's lifetime, change is inevitable in social, economic, and physical surroundings and occupants' needs (Russell & Moffatt, 2001). An adaptable building can respond to these various changes at a lower cost and stay in service longer rather than being abandoned and demolished. One of the critical concepts of adaptability is the 'shearing layers' proposed by Stewart Brand in his book How Buildings Learn: What Happens After They're Built (1994). It envisions a building as a set of 'shearing layers' that change at different rates. The more layers are connected, the more difficulty and cost of adaptation. Therefore, the high degree of layers' independence can help achieve a building's adaptability. On the other hand, timber has caught a renewed interest as a structural material due to its low embodied carbon, lightweight, and renewability features. Engineered timber products, such as cross-laminated timber and glue-laminated timber, significantly promote the development of timber structures in multi-storey buildings.

This paper aims to evaluate the adaptability of multi-storey timber buildings by analysing the independence of shearing layers, mainly focusing on the joint design between building elements. How does joint design affect the independence of shearing layers to achieve an adaptable timber building?

Brand's concept of 'shearing layers' includes 'stuff, space plan, services, skin, structure, and site' (Figure 1). This paper mainly focuses on the former five layers that belong to the 'building' in the narrow sense, as the 'site' layer is more relevant to the environment. During the analysis, the building will be divided into many 'building elements' (e.g. facade panels, CLT walls, doors...) according to different materials and functions. Figure 2 builds an extensive model based on Brand's model,

showing the relationship between building elements and shearing layers. Building elements can be considered subsets of building layers. The elements that relate to two layers' elements locate in the overlapping areas, and the ones having dependencies with all layers' elements locate in the middle. The dependencies between the shearing layers can be found by studying the dependencies between building elements.

Schmidt and Austin (2016) define three distinct dependency types: structural (e.g. gravitational, lateral), spatial (e.g. adjacency, circulation), and service (e.g. energy, water). This paper only focuses on the structural dependencies between building elements manifested at joints. Through analysis, it will determine which building elements belong to which layers and which joint positions primarily affect the dependencies between layers.

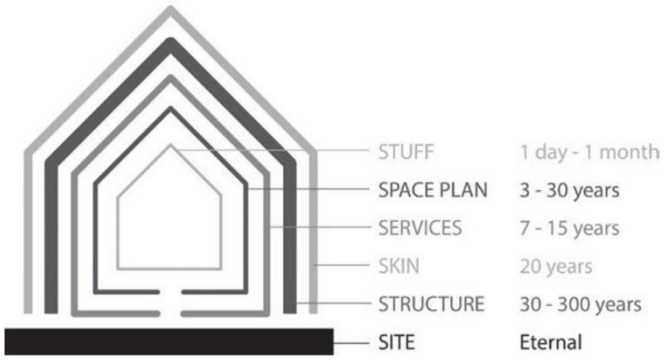


Figure 1. Shearing layers model. (Brand, 1994)

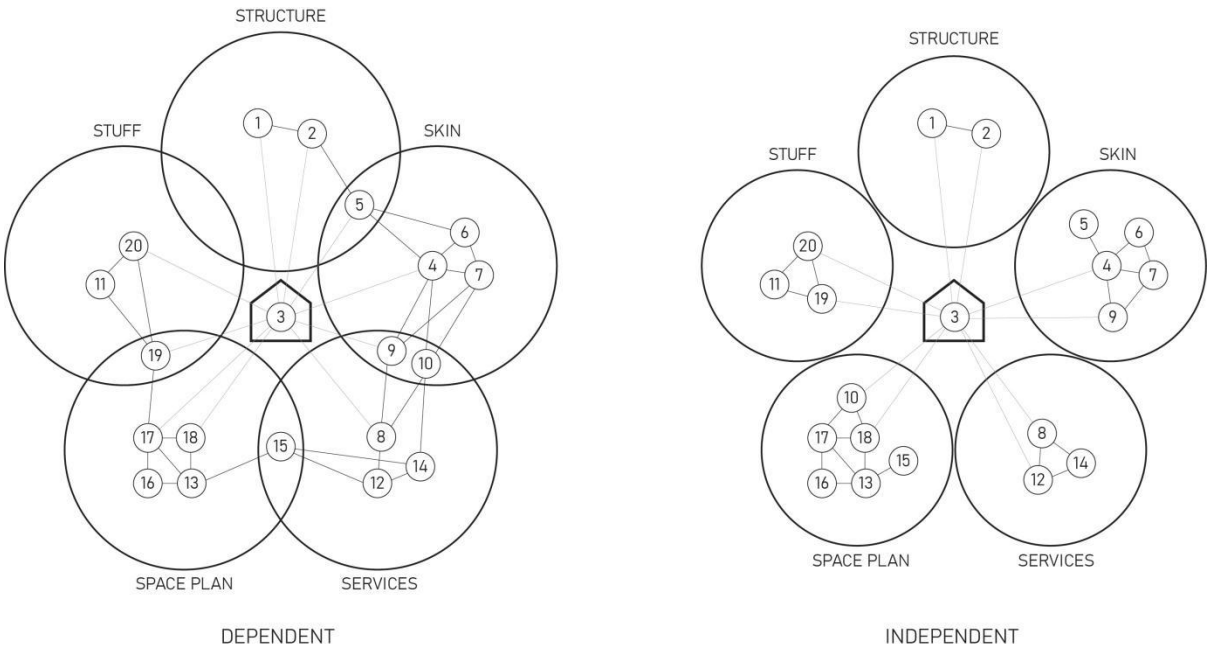


Figure 2. Shearing layers and building elements. (self made)

When considering a building's adaptability, it is essential to specify the 'change scene', that is, what is needed to change and why, as different change scenes require distinct adaptation strategies. Not all building layers have to be independent, and not all building elements must be structurally detached from others. A 'perfect' adaptable building that can respond to all changes does not exist and is not necessary. Therefore, the research will be limited under a scene of 'altering the function'. The scene is coming from the demand of the graduation project.

II. METHODOLOGY

In this paper, the case study will be the primary methodology of the research. Case 1, named Library and Seminar Centre BOKU Vienna, is claimed to be adaptable, while Case 2, the Pile up Giesshübel, seems non-adaptable. Both are multi-storey timber buildings. Another reason for choosing the two cases is that access to all their materials is available.

The Library and Seminar Centre BOKU Vienna, designed by SWAP Architektur and DELTA in 2020, is located on the University of Natural Resources and Life Sciences (BOKU) campus in Vienna, Australia. The four-storey building is built in a timber frame structure with prefabricated glue-laminated timber (GLT) and cross-laminated timber (CLT), with a concrete basement and stair core. The architects claim they made efforts to the adaptability of the building. Unconcealed service lines beneath the ceilings are common in all areas. BIM planning allowed them to coordinate with much greater ease than traditional planning. The knee-height window parapets that serve as seating also contain all electrical wiring and data cables, which enabled the architects to rigorously keep interior walls free of service lines to simplify future changes in the arrangement of walls. (Figure 3)

Figure 3. Pictures of the Library and Seminar Centre (SWAP Architekten, DELTA, 2020)

The Pile Up Giesshübel in Zürich, Switzerland, was renovated by Oxid Architektur from warehouse to apartment in 2013. A four-storey timber structure made of glued laminated timber is added to the original two-storey concrete base. In between, there are steel beams as the structural transformation layer. The existing five-metre grid of reinforced concrete beams repeats in the new timber storeys. The timber beams run through the depth of the building and form overhanging balconies, resting on timber supports that are integrated with the walls. These vertical supports grow wider from up to down due to increasing loads, but only on one axis to create the same wall thickness on all storeys. Between the beams are timber box ceilings with three-layer panel cladding, acting as reinforced ceiling panels. Besides, four concrete stairwells are constructed as extra support. Closed exterior walls are non-structural panel assemblies. (Figure 4)

Figure 4. Pictures of the Pile up Giesshübel. (Oxid Architektur, 2013)

The two cases will be analysed using the Dependency Structure Matrix (DSM) model. DSM is considered a powerful tool to reveal the complex interdependencies between elements in a building system (Schmidt & Austin, 2016).

An initial DSM is a square cell matrix, having the same elements in rows and columns, that shows relationships between elements in a system. The dependencies between every two elements are marked as '1' in the chart, while a blank cell means there is no dependency between those elements. DSM can be used for clustering and impact analysis. Clustering analysis involves rearranging elements into chunks that have high dependency internally and low dependency externally (Browning, 2001). One of the strategies is to isolate elements with high dependencies across several chunks as bus elements (Sharman & Yassine, 2004). Impact analysis studies the propagation impact when one element changes. The fewer impacted elements and propagation rounds, the smaller the caused impact. The research in this paper includes both two parts. (Figure 5)

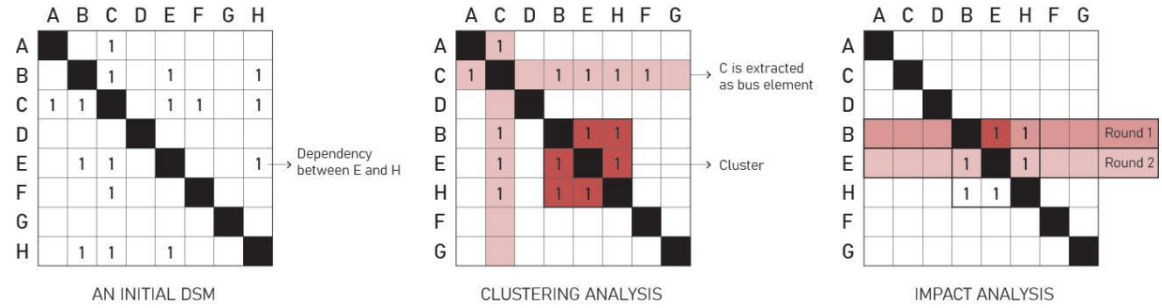


Figure 5. Examples of how DSM works. (self made)

The clustering analysis in Chapter III aims to study how independent the shearing layers of the two cases are. The buildings will be firstly divided into elements listed in the rows and columns in the initial DSMs, and each element will be subjectively classified into one shearing layer depending on positions and functions. Then, the dependencies between elements are marked in the matrix. Finally, the elements are rearranged and redivided into layers depending on the marked dependencies. After the independent analysis of the two cases, a comparison will be made as a small conclusion.

The impact analysis in Chapter IV is based on the result of the clustering analysis. It aims to verify if the two cases can adapt to the changes and to find what joint design help or hinder the adaptability under the scene of altering the function. Firstly, what building elements might need to be altered in the scene will be clarified. Secondly, the propagation caused by elements' change will be examined and highlighted in colours based on the DSM charts. In each DSM, the propagation impact of altering one building element is shown in red colours (from dark to light) that indicate the sequences. Dependencies that trigger the propagation are marked in the darkest red (Figure 5). The analysis can clearly show if the impact would pass across layers and which joint positions promote or prevent propagation. Finally, the joint details drawings related to the building elements are analysed in the same colour system as the DSM, illustrating why the dependencies trigger or do not trigger the propagation.

After the two parts of research, the conclusion will be made in Chapter V to answer the main question about how joint design affects the independence of shearing layers to achieve an adaptable timber building under the scene of altering the function.

III. CLUSTERING ANALYSIS

3.1. Case 1: Library and Seminar Centre BOKU Vienna

Appendix 1 and Appendix 2 are the initial and clustered DSM of Case 1, respectively. In general, the following findings are shown:

1. In Appendix 2, most elements can be well clustered. One layer includes single or multiple clusters. For example, the 'space plan' layer includes two clusters, the cluster with elements '14, 24, 23, 18' and the one with elements '13, 17, 31, 22, 20, 21'.

2. Some elements are divided into different layers in Appendix 1 and Appendix 2, such as 'Spruce window seats (13)' moved from the 'skin' layer to the 'space plan' layer. This is because the element depends more on space plan elements than facade elements.

3. Some elements are marked in two layers simultaneously. For example, 'CLT ceiling (roof) (14)' is classified into 'skin (roof)' and 'space plan' layers, resulting from its similar degree of dependency on the elements in both layers. It can be seen as a connection element, causing dependency between two layers.

4. Service elements 'Electrical wiring and data cables (17)' and 'Ventilation system (18)' are combined with the 'space plan' layer, whereas the element 'Water pipes (19)' strongly depends on elements in the 'stuff' layer.

5. 'Concrete core with staircase (2)' and 'Glulam timber structural frame (3)' are extracted as bus elements due to their high dependencies with all layers. It shows that 'structure' is the base of all the other layers, and the change of 'structure' elements might impact the whole building.

3.2. Case 2: Pile up Giesshübel

Appendix 3 and Appendix 4 are the initial DSM and clustered DSM of Case 2, respectively. It has to be clarified that the analysis focuses on the new timber storeys and considers the concrete base as one element of 'Existing concrete storeys and foundation (1)'. In the analysis, the following findings are figured out:

1. According to Appendix 4, the building elements of Case 2 cannot be well organized in clusters. Most of the elements have complex interdependencies with the others.

2. Except for structural elements, the service element 'Drainage and pipes (20)' is extracted as a bus element because it depends on all the other layers. The other two service elements, 'Ventilation system (19)' and 'Electrical cables (18)', are included in the 'space plan' layer.

3. The 'skin (balcony)' layer is independent of other layers.

4. The cluster with elements 'Partition walls (21), Flooring finishes (23), and Doors (interior) (22)' connects the 'space plan' and 'stuff' layer.

3.3. Comparison

Comparing the two cases, the shearing layers of Case 1 are much more independent than the ones of Case 2. The building elements of Case 1 can be well clustered, meaning that each element only depends on a few elements and is generally detached. By contrast, the building elements of Case 2 have more complex interdependencies. Another difference between the two cases is the way of dealing with services. In Case 1, the electrical cables, ventilation system and drainage pipes are carefully designed to have fewer dependencies on other elements, while Case 2 has no special consideration. As to similarity, both cases indicate an independent skin layer.

In the next chapter, how their designs affect adaptability will be analysed more deeply.

IV. IMPACT ANALYSIS

At the beginning of this chapter, it has to be clarified what layers and building elements might be altered under the scene of altering the function.

1. Space plan. Depending on distinct programs, the space plan may need to change by rearranging the partition walls.

2. Skin. The curtain walls might be altered to other non-transparent materials when transforming a public building into housing. In some cases, the balconies are eliminated and merged with interior spaces.

3. Services. Services usually represent energy, ventilation and water systems, likely to shift with functional transformation.

4.1. Space Plan

Appendix 5 and Appendix 6 analyse the impact of altering the partition walls of the two cases based on the clustered DSMs from Chapter III.

Appendix 5 shows that altering 'Partition walls (23)' in Case 1 only impacts one element, 'Doors (interior) (24)'. It is normal because the doors are integrated with the walls. Interestingly, six other dependencies do not cause any impact. They are dependencies with 'Concrete core with staircase (2), Glulam timber structural frame (3), CLT ceiling (roof) (14), Ventilation system (18), CLT floor panels (20), and Flooring finishes and insulation (21)'. It is a result of the detached joint design shown in Appendix 7. The partition wall is constructed independently of the flooring, the connection element between the 'space plan' and 'stuff' layers.

In Appendix 6, the change of 'Partition walls (21)' in Case 2 leads to an extensive range of impact on thirteen elements crossing three layers: 'space plan', 'services' and 'stuff'. The integrated plasterboard cladding causes the propagation from walls to the flooring and ceiling (Appendix 7). After that, the impact on the flooring and ceiling is propagated to the furniture, lighting, fixtures, cables and pipes. Besides, the kitchen cabinets and wardrobes are influenced due to their integration with the walls.

It can be found that the distinct joint designs between walls and floors result in a considerably different range of impact. Case 1 considers the wall and the floor as separate components, whereas Case 2 constructs them integrated (Appendix 7). As a result, Case 1 shows better adaptability than Case 2 when altering the partition walls.

4.2. Skin

This section analyses the impact of altering skin elements in the two cases. In each case, two skin elements are chosen to be studied. In Case 1, the change of element 'Curtain walls (6)' impacts six elements within the 'skin (facade)' layer (Appendix 8). Similarly, the change of element 'Larch facade panels (4)' impacts two elements within the same layer (Appendix 9). In Case 2, elements 'Facade panel assembles (6)' and 'Timber sliding doors (12)' both impacts three elements within the 'skin (balcony)' layer (Appendix 10 & Appendix 11).

Both cases present minor impacts under the scene of altering the skin elements. Appendix 12 and Appendix 13 illustrate that their facade joints are detachable, preventing the impact from propagating.

4.3. Services

The following analysis concerns the impact of altering or updating the electrical cables and water systems (drainage and water pipes).

In Appendix 14, Case 1 shows good adaptability when altering the 'Electrical wiring and data cables (17)'. It results from the elaborate design of the spruce window seats that contains the cables and frees them from the walls (Appendix 18). In Appendix 15, the change of 'Water pipes (19)' has a more extensive range of impact. The water system is integrated with the flooring finishes, which is a traditional construction method (Appendix 18). Although an access port is left for maintenance,

substantial changes such as altering the positions and updating the system require the reconstruction of flooring and walls. Nevertheless, this range of reconstruction is acceptable compared to Case 2.

As shown in Appendix 16 and Appendix 17, Case 2 needs to improve adaptability when it comes to services. The electrical cables are located within the ceiling finishes and the partition walls (Appendix 19), so its impact range is similar to changing the walls (Appendix 6). The 'Drainage and pipes (20)' of Case 2 are closely combined with the structural element 'Timber box ceiling with three-layer panel cladding (4)' (Appendix 19). Both are bus elements and have strong dependencies with all the other layers, which results in a wide-ranging impact on the whole building (Appendix 17).

V. CONCLUSIONS

The paper compared two cases, the Library and Seminar Centre (Case 1) and Pile up Giesshübel (Case 2), to figure out how joint design affects the adaptability under the scene of altering the function using the DSM tool.

The clustering analysis studied the dependencies between the building elements and classified elements into shearing layers. It found that Case 1 has fewer dependencies between elements and can be better decomposed into independent layers than Case 2.

The impact analysis studied the propagation impact of chosen elements in the space plan, skin and services layers. It proved that Case 1 is much more adaptable than the other case when changing the space plan and electrical services, resulting from its detached joint design in partition walls and electrical cables. Its traditional design in the water system shows limited adaptability, but it is still better than impacting the whole building in Case 2. Besides, the two cases both show good adaptability when changing the skin.

Figure 6 concludes the findings of two cases using the extensive model based on Brand's model. The detached joints (grey lines in Figure 6) prevent impacts from propagating between elements. As indicated in the graphics, the connection and bus elements that have dependencies with multiple layers' elements need to be paid more attention to because the change of these elements has extensive impacts. Detached joint designs around them can considerably reduce propagated impacts. For example, the impact of altering the partition walls in Case 1 is reduced by the detached joint design between the wall and flooring, shown as the grey line between elements 21 and 23 in Figure 6. However, the detached joints around the bus elements can only hinder propagation from other elements towards the bus elements. The change of the bus elements still impacts all the elements depending on them, as shown in the impact analysis of 'Drainage and pipes (20)' in Case 2. Therefore, the elements that need to be changed cannot be bus elements.

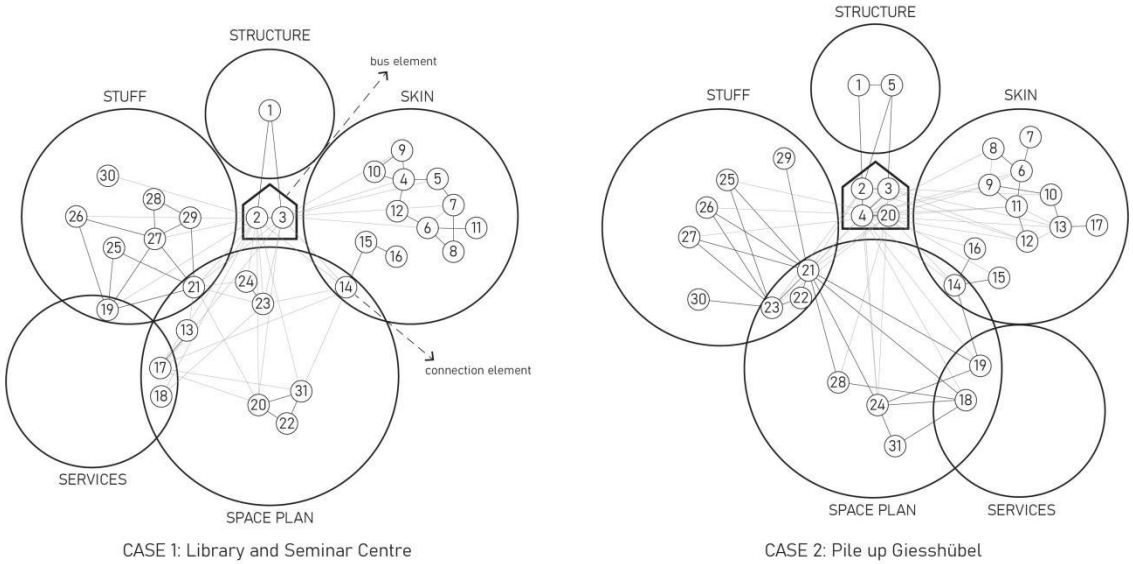


Figure 6. Conclusion of the dependencies of building elements and layers of two cases. (self made)

The paper provides a methodology, based on Brand's 'shearing layers' model, to verify an existing building's adaptability or assist in designing a new adaptable building. It helps locate the critical joint positions that affect adaptability in a specific scene. Detached joint design in these positions can significantly promote adaptability, which is unnecessary in other unimportant positions. Except for the scene discussed in the paper, the method can be applied to other scenes in further research.

REFERENCES

1. Schmidt III, R., & Austin, S. (2016). Adaptable Architecture: Theory and practice (1st ed.). Routledge. https://doi-org.tudelft.idm.oclc.org/10.4324/9781315722931
2. Brand, S. (1994). How Buildings Learn: What Happens After They're Built. ISBN 978-0140139969.
3. Mohammad, M., Douglas, B., Rammer, D. & Pryor, S.E. (2012). CLT Handbook: Cross-laminated timber. Chapter 5: Connection in Cross-Laminated Timber Buildings. ISBN 978-0864885548.
4. Kaufmann, H., Krötsch, S. & Winter, S. (2018). Manual of Multistorey Timber Construction. München: DETAIL. https://doi-org.tudelft.idm.oclc.org/10.11129/9783955533953
5. Herzog, T., Natterer, J., Schweitzer, R., Volz, M., & Winter, W. (2004). Timber Construction Manual. Walter de Gruyter GmbH. https://ebookcentral-proquest-com.tudelft.idm.oclc.org/lib/delft/reader.action?docID=1075578
6. Sandra, H. (2022). Holz Bauten Timber Buildings. ISBN 978-3955535872.
7. Russell, P. & Moffatt, S. (2001). Assessing Buildings for Adaptability. IEA Annex 31 Energy-Related Environmental Impact of Buildings.
8. Scott, L.M. & Towey, B. (2013). Developments in Closed Panel Timber Frame Connection.
9. Hua, H., Hovestadt, L. & Li, B. (2022). Reconfigurable Modular System of Prefabricated Timber Grids. https://doi.org/10.1016/j.cad.2022.103230
10. BauBuche. (n.d.). https://www.pollmeier.com/products/baubuche-about
11. Laboratory for Product Development and Lightweight Design. (n.d.). The Design Structure Matrix. https://dsmweb.org/
12. SWAP Architekten, DELTA. (2020). Library and Seminar Centre BOKU Vienna. Archdaily. https://www.archdaily.com/955587/library-and-seminar-centre-boku-vienna-swap-architekten-plus-delta?ad_medium=gallery
13. SWAP Architekten. (2020). Ilse Wallentin Haus. https://architektur.swap-zt.com/projects/boku-wien
14. Oxid Architektur. (2013). Pile up Giesshübel. https://oxid-architektur.ch/projekt/2/pile-up-giesshuebel

APPENDIX. ANALYSIS RESULTS

Layers	Element Names		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
STRUCTURE	Concrete foundation	1		1	1																												
	Concrete core with staircase	2	1		1											1			1	1	1	1	1		1	1		1	1			1	1
	Glulam timber structural frame	3	1	1		1	1	1	1		1					1			1			1	1		1								
SKIN	Larch facade panels	4			1		1				1	1		1																			
	Insulation and sealant (exterior wall)	5			1	1			1																								
	Curtain walls (triple glazing in spruce frame)	6			1				1	1			1	1																			
	CLT walls (exterior)	7			1		1	1		1					1								1										
	Doors (exterior)	8						1	1																								
	Larch lesene	9			1	1						1																					
	Larch mullion with sheet metal coping	10				1					1																						
	Window blinds (indoor)	11						1																									
	Window blinds (outdoor)	12				1		1																									
	Spruce window seats	13							1										1				1										
	CLT ceiling (roof)	14		1	1												1		1						1								1
	Insulation and sealant (roof)	15														1		1															
	Aluminum coping (roof)	16															1																
SERVICES	Electrical wiring and data cables	17		1	1										1	1														1			1
	Ventilation system	18		1																					1								
	Water pipes	19		1																			1				1	1	1				
SPACE PLAN	CLT floor panels	20		1	1																		1	1	1								1
	Flooring finishes and insulation	21		1	1				1						1						1	1			1	1	1		1		1		
	Acoustic ceiling	22																				1											1
	Partition walls (timber frame and various panels)	23		1	1											1				1		1	1			1							
	Doors (interior)	24		1																			1		1								
STUFF	Toilet fixtures	25																			1		1										
	Plumbing accessories (faucet, pipes)	26		1																	1								1				
	Kitchen cabinets and sinks	27		1																	1		1					1		1			
	Appliances	28																	1										1		1		
	Furnitures	29																					1							1			
	Hanging greenery	30		1																													
	Lighting	31		1												1			1			1		1									

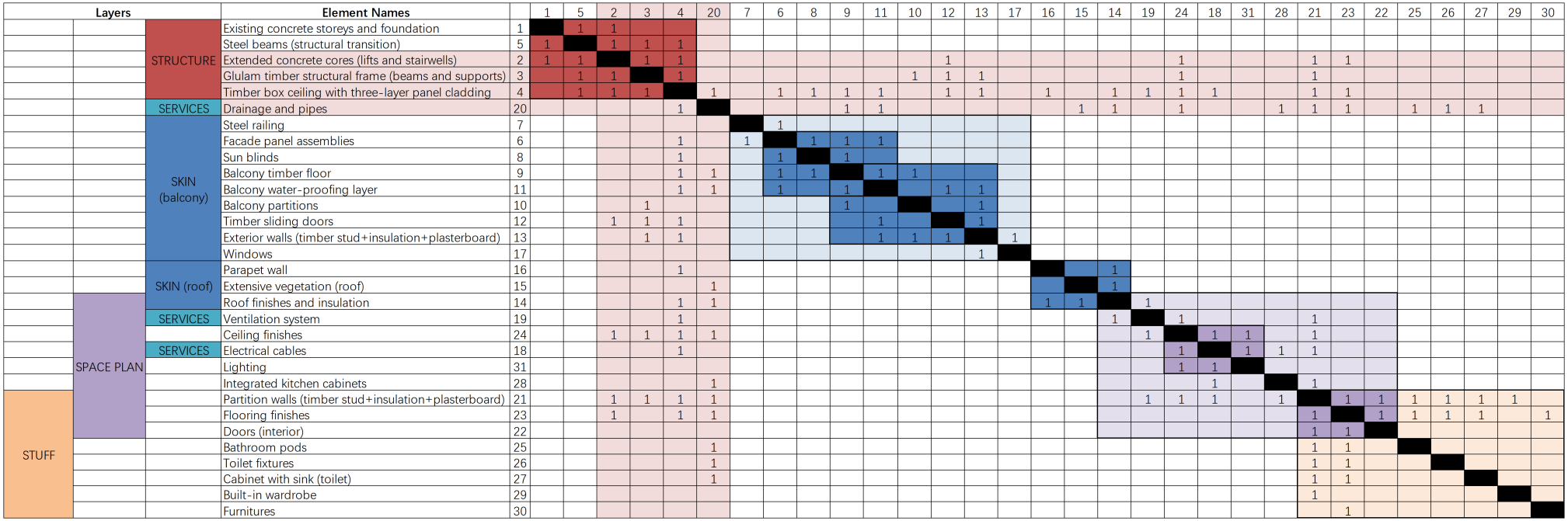
Appendix 1. Initial DSM of Case 1: Library and Seminar Centre. (self made)

Layers			Element Names		1	2	3	9	10	4	12	5	6	7	8	11	15	16	14	24	23	18	13	17	31	22	20	21	19	27	25	26	28	29	30
		STRUCTURE	Concrete foundation	1		1	1																												
		STRUCTURE	Concrete core with staircase	2	1		1												1	1	1	1		1	1		1	1	1	1		1			1
		STRUCTURE	Glulam timber structural frame	3	1	1		1		1		1	1	1					1		1			1			1	1							
		SKIN (facade)	Larch lesene	9			1		1	1																									
		SKIN (facade)	Larch mullion with sheet metal coping	10				1		1																									
		SKIN (facade)	Larch facade panels	4			1	1	1		1	1																							
		SKIN (facade)	Window blinds (outdoor)	12						1			1																						
		SKIN (facade)	Insulation and sealant (exterior wall)	5			1			1				1																					
		SKIN (facade)	Curtain walls (triple glazing in spruce frame)	6			1				1			1	1	1																			
		SKIN (facade)	CLT walls (exterior)	7			1					1	1		1																				
		SKIN (facade)	Doors (exterior)	8									1	1																					
		SKIN (facade)	Window blinds (indoor)	11									1																						
		SKIN (roof)	Insulation and sealant (roof)	15														1	1																
		SKIN (roof)	Aluminum coping (roof)	16													1																		
	SPACE PLAN		CLT ceiling (roof)	14		1	1										1				1			1	1										
	SPACE PLAN		Doors (interior)	24		1															1							1							
	SPACE PLAN		Partition walls (timber frame and various panels)	23		1	1												1	1		1					1	1							
	SPACE PLAN	SERVICES	Ventilation system	18		1															1														
	SPACE PLAN		Spruce window seats	13																			1					1							
	SPACE PLAN	SERVICES	Electrical wiring and data cables	17		1	1												1				1		1		1					1		
	SPACE PLAN		Lighting	31		1													1					1		1	1							
	SPACE PLAN		Acoustic ceiling	22																					1		1							
	SPACE PLAN		CLT floor panels	20		1	1														1			1	1	1		1						
	SPACE PLAN		Flooring finishes and insulation	21		1	1													1	1		1				1		1	1	1			1	
STUFF		SERVICES	Water pipes	19		1																						1		1	1	1			
STUFF			Kitchen cabinets and sinks	27		1																						1	1			1	1		
STUFF			Toilet fixtures	25																								1	1						
STUFF			Plumbing accessories (faucet, pipes)	26		1																							1	1					
STUFF			Appliances	28																			1							1			1	1	
STUFF			Furnitures	29																								1					1		
STUFF			Hanging greenery	30		1																													

Appendix 2. Clustered DSM of Case 1: Library and Seminar Centre. (self made)

Layers	Element Names		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	24	17	18	19	20	21	22	23	25	26	27	28	29	30	31
STRUCTURE	Existing concrete storeys and foundation	1		1			1																										
	Extended concrete cores (lifts and stairwells)	2	1		1	1	1							1									1		1	1							
	Glulam timber structural frame (beams and supports)	3		1		1	1					1		1	1								1			1							
	Timber box ceiling with three-layer panel cladding	4		1	1		1	1		1	1		1	1	1	1		1		1	1	1	1		1	1							
	Steel beams (structural transition)	5	1	1	1	1																											
SKIN	Facade panel assemblies	6				1			1	1	1		1																				
	Steel railing	7						1																									
	Sun blinds	8				1		1			1																						
	Balcony timber floor	9				1		1		1		1	1									1											
	Balcony partitions	10			1						1				1																		
	Balcony water-proofing layer	11				1		1			1			1	1							1											
	Timber sliding doors	12		1	1	1							1		1																		
	Exterior walls (timber stud+insulation+plasterboard)	13			1	1						1	1	1					1				1		1	1							
	Roof finishes and insulation	14				1											1	1			1	1											
	Extensive vegetation (roof)	15														1						1											
	Parapet wall	16				1										1																	
	Windows	17													1																		
SERVICES	Electrical cables	18				1																1								1			1
	Ventilation system	19				1										1							1		1								
	Drainage and pipes	20				1					1		1			1	1			1			1		1	1	1	1	1	1			
SPACE PLAN	Partition walls (timber stud+insulation+plasterboard)	21		1	1	1									1						1	1		1	1	1	1	1	1	1		
	Doors (interior)	22																					1		1								
	Flooring finishes	23		1		1									1						1		1	1			1	1	1			1	
	Ceiling finishes	24		1	1	1									1					1	1	1	1									1
STUFF	Bathroom pods	25																				1	1		1								
	Toilet fixtures	26																				1	1		1								
	Cabinet with sink (toilet)	27																				1	1		1								
	Integrated kitchen cabinets	28																		1		1	1										
	Built-in wardrobe	29																					1										
	Furnitures	30																							1								
	Lighting	31																		1						1							

Appendix 3. Initial DSM of Case 2: Pile up Giesshübel. (self made)



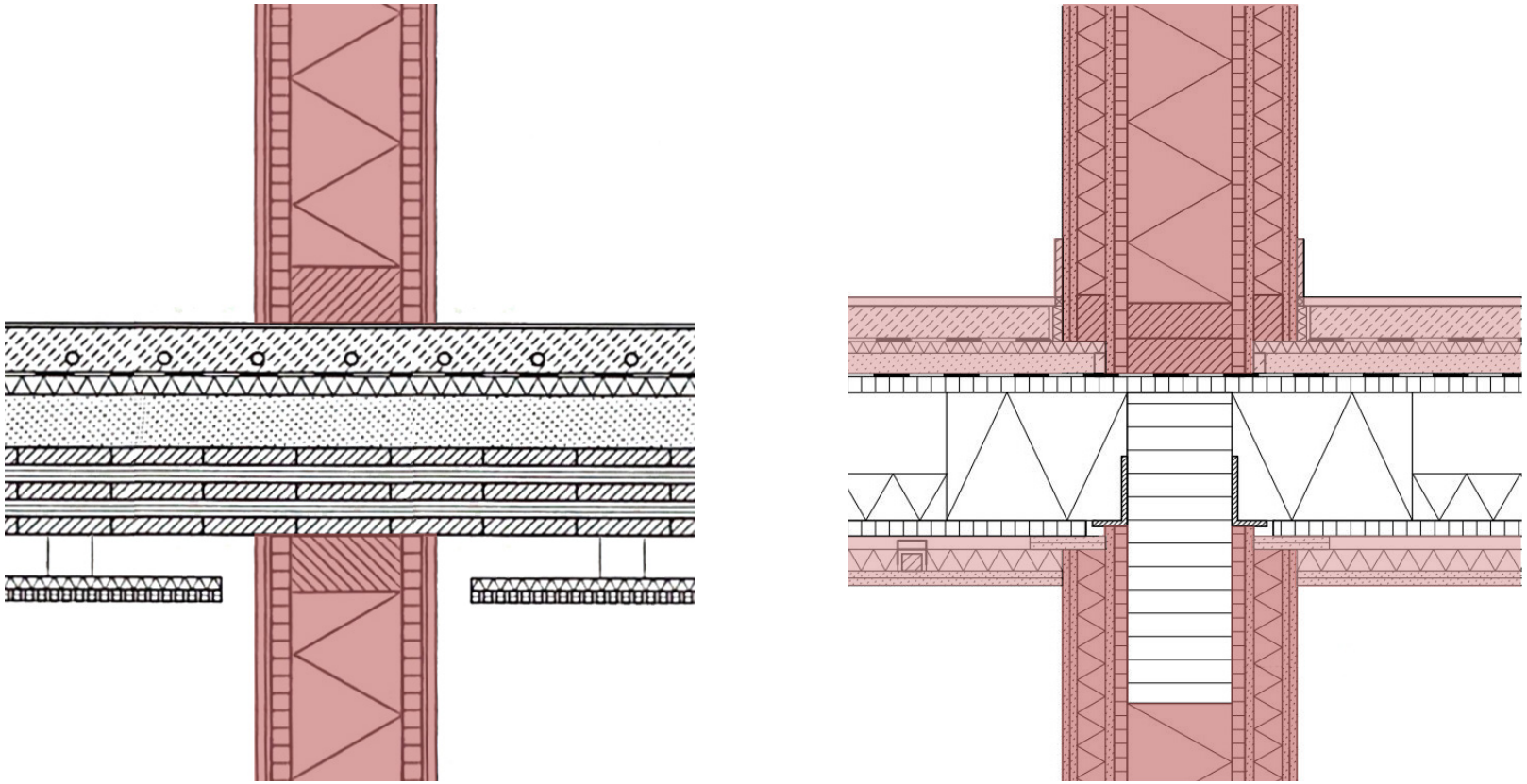
Appendix 4. Clustered DSM of Case 2: Pile up Giesshübel. (self made)

Layers		Element Names		1	2	3	9	10	4	12	5	6	7	8	11	15	16	14	24	23	18	13	17	31	22	20	21	19	27	25	26	28	29	30	
	STRUCTURE	Concrete foundation	1		1	1																													
		Concrete core with staircase	2	1		1												1	1	1	1		1	1		1	1	1	1		1			1	
		Glulam timber structural frame	3	1	1		1		1		1	1	1					1		1			1			1	1								
	SKIN (facade)	Larch lesene	9			1		1	1																										
		Larch mullion with sheet metal coping	10				1		1																										
		Larch facade panels	4			1	1	1		1	1																								
		Window blinds (outdoor)	12						1			1																							
		Insulation and sealant (exterior wall)	5			1			1				1																						
		Curtain walls (triple glazing in spruce frame)	6			1				1			1	1	1																				
		CLT walls (exterior)	7			1					1	1		1																					
		Doors (exterior)	8									1	1																						
		Window blinds (indoor)	11									1																							
	SKIN (roof)	Insulation and sealant (roof)	15														1	1																	
		Aluminum coping (roof)	16													1																			
	SPACE PLAN	CLT ceiling (roof)	14		1	1										1				1			1	1											
		Doors (interior)	24		1															1							1								ROUND 2
		Partition walls (timber frame and various panels)	23		1	1												1	1		1					1	1								ROUND 1
	SERVICES	Ventilation system	18		1															1															
		Spruce window seats	13																				1				1								
	SERVICES	Electrical wiring and data cables	17		1	1												1				1		1		1						1			
		Lighting	31		1													1					1		1	1									
		Acoustic ceiling	22																					1		1									
		CLT floor panels	20		1	1														1			1	1	1		1								
		Flooring finishes and insulation	21		1	1													1	1		1				1		1	1	1			1		
	SERVICES	Water pipes	19		1																						1		1	1	1				
		Kitchen cabinets and sinks	27		1																						1	1			1	1			
STUFF		Toilet fixtures	25																								1	1							
		Plumbing accessories (faucet, pipes)	26		1																							1	1						
		Appliances	28																				1						1				1		
		Furnitures	29																								1					1			
		Hanging greenery	30		1																														

Appendix 5. Impact analysis on Case 1: Library and Seminar Centre (partition walls). (self made)

Layers		Element Names		1	5	2	3	4	20	7	6	8	9	11	10	12	13	17	16	15	14	19	24	18	31	28	21	23	22	25	26	27	29	30	
	STRUCTURE	Existing concrete storeys and foundation	1		1	1																													
		Steel beams (structural transition)	5	1		1	1	1																											
		Extended concrete cores (lifts and stairwells)	2	1	1		1	1								1							1				1	1							
		Glulam timber structural frame (beams and supports)	3		1	1		1							1	1	1						1				1								
		Timber box ceiling with three-layer panel cladding	4		1	1	1		1		1	1	1	1		1	1		1		1	1	1	1			1	1							
	SERVICES	Drainage and pipes	20					1					1	1							1	1		1			1	1	1		1	1	1			ROUND 3
	SKIN (balcony)	Steel railing	7								1																								
		Facade panel assemblies	6					1		1		1	1	1																					
		Sun blinds	8					1			1		1																							
		Balcony timber floor	9					1	1		1	1		1	1																					
		Balcony water-proofing layer	11					1	1		1		1			1	1																			
		Balcony partitions	10				1						1				1																			
		Timber sliding doors	12			1	1	1						1			1																			
		Exterior walls (timber stud+insulation+plasterboard)	13				1	1						1	1	1		1																		
		Windows	17														1																			
	SKIN (roof)	Parapet wall	16					1													1															
		Extensive vegetation (roof)	15						1												1															
	SPACE PLAN	Roof finishes and insulation	14					1	1										1	1		1														
	SERVICES	Ventilation system	19					1													1		1				1									
		Ceiling finishes	24			1	1	1	1													1		1	1		1									ROUND 2
	SERVICES	Electrical cables	18					1															1		1	1	1									
		Lighting	31																				1	1												ROUND 3
		Integrated kitchen cabinets	28						1															1			1									ROUND 2
		Partition walls (timber stud+insulation+plasterboard)	21			1	1	1	1													1	1	1		1		1	1	1	1	1	1			ROUND 1
		Flooring finishes	23			1		1	1																		1		1	1	1			1		ROUND 2
		Doors (interior)	22																								1	1								
STUFF		Bathroom pods	25						1																		1	1								
		Toilet fixtures	26						1																		1	1								ROUND 3
		Cabinet with sink (toilet)	27						1																		1	1								
		Built-in wardrobe	29																								1									ROUND 2
		Furnitures	30																									1								ROUND 3

Appendix 6. Impact analysis on Case 2: Pile up Giesshübel (partition walls). (self made)



Appendix 7. Details of partition walls of Case 1 (left) and Case 2 (right).
(self analysed on drawings from Sandra, H., 2022 and Kaufmann, H., Krötsch, S. & Winter, S., 2018)

Layers		Element Names		1	2	3	9	10	4	12	5	6	7	8	11	15	16	14	24	23	18	13	17	31	22	20	21	19	27	25	26	28	29	30	
	STRUCTURE	Concrete foundation	1		1	1																													
	STRUCTURE	Concrete core with staircase	2	1		1												1	1	1	1		1	1		1	1	1	1		1			1	
	STRUCTURE	Glulam timber structural frame	3	1	1		1		1		1	1	1					1		1			1			1	1								
	SKIN (facade)	Larch lesene	9			1		1	1																										ROUND 4
	SKIN (facade)	Larch mullion with sheet metal coping	10				1		1																										
	SKIN (facade)	Larch facade panels	4			1	1	1		1	1																								ROUND 3
	SKIN (facade)	Window blinds (outdoor)	12						1			1																						ROUND 2
	SKIN (facade)	Insulation and sealant (exterior wall)	5			1			1				1																						
	SKIN (facade)	Curtain walls (triple glazing in spruce frame)	6			1				1			1	1	1																				ROUND 1
	SKIN (facade)	CLT walls (exterior)	7			1					1	1		1																					
	SKIN (facade)	Doors (exterior)	8									1	1																						ROUND 2
	SKIN (facade)	Window blinds (indoor)	11									1																							
	SKIN (roof)	Insulation and sealant (roof)	15														1	1	1																
	SKIN (roof)	Aluminum coping (roof)	16													1																			
	SPACE PLAN	CLT ceiling (roof)	14		1	1										1				1			1	1											
	SPACE PLAN	Doors (interior)	24		1															1							1								
	SPACE PLAN	Partition walls (timber frame and various panels)	23		1	1												1	1		1					1	1								
	SERVICES	Ventilation system	18		1															1															
	SPACE PLAN	Spruce window seats	13																				1				1								
	SERVICES	Electrical wiring and data cables	17		1	1												1				1		1		1						1			
	SPACE PLAN	Lighting	31		1													1					1		1	1									
	SPACE PLAN	Acoustic ceiling	22																					1		1									
	SPACE PLAN	CLT floor panels	20		1	1															1		1	1	1		1								
	SPACE PLAN	Flooring finishes and insulation	21		1	1													1	1		1				1		1	1	1			1		
	SERVICES	Water pipes	19		1																						1		1	1	1				
STUFF		Kitchen cabinets and sinks	27		1																						1	1			1	1			
STUFF		Toilet fixtures	25																								1	1							
STUFF		Plumbing accessories (faucet, pipes)	26		1																							1	1						
STUFF		Appliances	28																				1						1				1		
STUFF		Furnitures	29																								1					1			
STUFF		Hanging greenery	30		1																														

Appendix 8. Impact analysis on Case 1: Library and Seminar Centre (curtain walls). (self made)

Layers		Element Names		1	2	3	9	10	4	12	5	6	7	8	11	15	16	14	24	23	18	13	17	31	22	20	21	19	27	25	26	28	29	30	
	STRUCTURE	Concrete foundation	1		1	1																													
	STRUCTURE	Concrete core with staircase	2	1		1												1	1	1	1		1	1		1	1	1	1		1			1	
	STRUCTURE	Glulam timber structural frame	3	1	1		1		1		1	1	1					1		1			1			1	1								
	SKIN (facade)	Larch lesene	9			1		1	1																										ROUND 2
	SKIN (facade)	Larch mullion with sheet metal coping	10				1		1																										
	SKIN (facade)	Larch facade panels	4			1	1	1		1	1																								ROUND 1
	SKIN (facade)	Window blinds (outdoor)	12						1			1																							
	SKIN (facade)	Insulation and sealant (exterior wall)	5			1			1				1																						
	SKIN (facade)	Curtain walls (triple glazing in spruce frame)	6			1				1			1	1	1																				
	SKIN (facade)	CLT walls (exterior)	7			1					1	1		1																					
	SKIN (facade)	Doors (exterior)	8									1	1																						
	SKIN (facade)	Window blinds (indoor)	11									1																							
	SKIN (roof)	Insulation and sealant (roof)	15														1	1	1																
	SKIN (roof)	Aluminum coping (roof)	16													1																			
	SPACE PLAN	CLT ceiling (roof)	14		1	1										1				1			1	1											
	SPACE PLAN	Doors (interior)	24		1															1							1								
	SPACE PLAN	Partition walls (timber frame and various panels)	23		1	1												1	1		1					1	1								
	SERVICES	Ventilation system	18		1															1															
	SPACE PLAN	Spruce window seats	13																				1				1								
	SERVICES	Electrical wiring and data cables	17		1	1												1				1		1		1						1			
	SPACE PLAN	Lighting	31		1													1					1		1	1									
	SPACE PLAN	Acoustic ceiling	22																					1		1									
	SPACE PLAN	CLT floor panels	20		1	1															1		1	1	1		1								
	SPACE PLAN	Flooring finishes and insulation	21		1	1													1	1		1				1		1	1	1			1		
	SERVICES	Water pipes	19		1																						1		1	1	1				
STUFF		Kitchen cabinets and sinks	27		1																						1	1			1	1			
STUFF		Toilet fixtures	25																								1	1							
STUFF		Plumbing accessories (faucet, pipes)	26		1																							1	1						
STUFF		Appliances	28																				1						1				1		
STUFF		Furnitures	29																								1					1			
STUFF		Hanging greenery	30		1																														

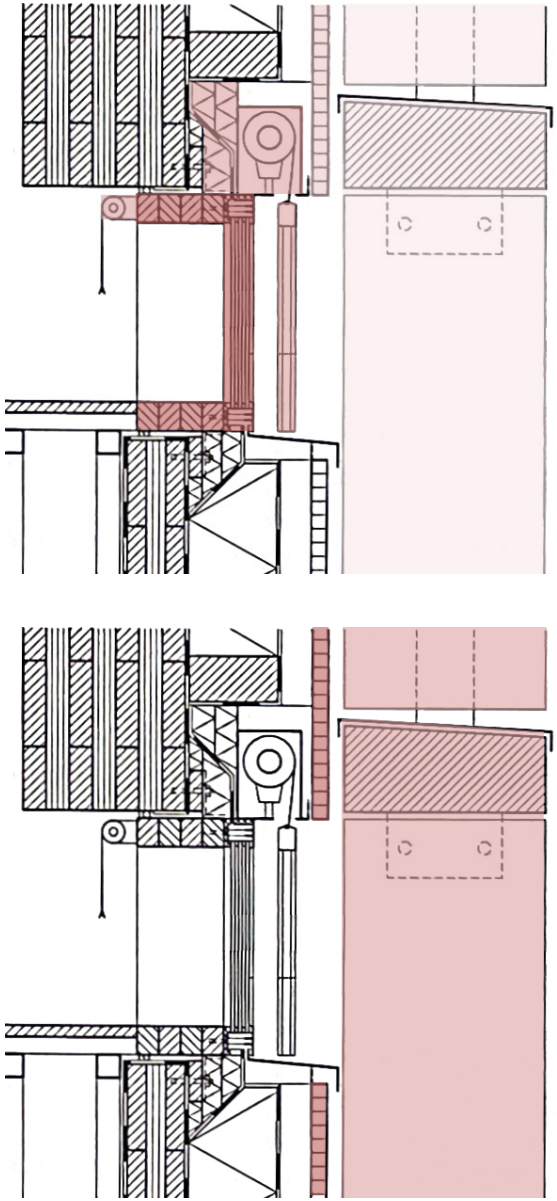
Appendix 9. Impact analysis on Case 1: Library and Seminar Centre (larch facade panel). (self made)

Layers			Element Names		1	5	2	3	4	20	7	6	8	9	11	10	12	13	17	16	15	14	19	24	18	31	28	21	23	22	25	26	27	29	30	
			Existing concrete storeys and foundation	1		1	1																													
			Steel beams (structural transition)	5	1		1	1	1																												
		STRUCTURE	Extended concrete cores (lifts and stairwells)	2	1	1		1	1								1							1				1	1							
			Glulam timber structural frame (beams and supports)	3		1	1		1							1	1	1						1				1								
			Timber box ceiling with three-layer panel cladding	4		1	1	1		1		1	1	1	1		1	1		1		1	1	1	1			1	1							
		SERVICES	Drainage and pipes	20					1					1	1						1	1	1		1			1	1	1		1	1	1		
			Steel railing	7								1																							ROUND 2
			Facade panel assemblies	6					1		1		1	1	1																				ROUND 1
			Sun blinds	8					1			1		1																				ROUND 2
		SKIN (balcony)	Balcony timber floor	9					1	1		1	1		1	1																			
			Balcony water-proofing layer	11					1	1		1		1			1	1																		ROUND 2
			Balcony partitions	10				1						1				1																		
			Timber sliding doors	12			1	1	1						1			1																		
			Exterior walls (timber stud+insulation+plasterboard)	13				1	1						1	1	1		1																	
			Windows	17														1																		
			Parapet wall	16					1													1														
		SKIN (roof)	Extensive vegetation (roof)	15						1												1														
			Roof finishes and insulation	14					1	1											1	1		1												
		SERVICES	Ventilation system	19					1														1		1				1							
			Ceiling finishes	24			1	1	1	1														1		1	1		1							
		SERVICES	Electrical cables	18					1																1		1	1	1							
	SPACE PLAN		Lighting	31																					1	1									
			Integrated kitchen cabinets	28						1																1			1							
			Partition walls (timber stud+insulation+plasterboard)	21			1	1	1	1													1	1	1		1		1	1	1	1	1	1		
			Flooring finishes	23			1		1	1																		1		1	1	1	1		1	
			Doors (interior)	22																								1	1							
STUFF			Bathroom pods	25						1																		1	1							
			Toilet fixtures	26						1																		1	1							
			Cabinet with sink (toilet)	27						1																		1	1							
			Built-in wardrobe	29																								1								
			Furnitures	30																									1							

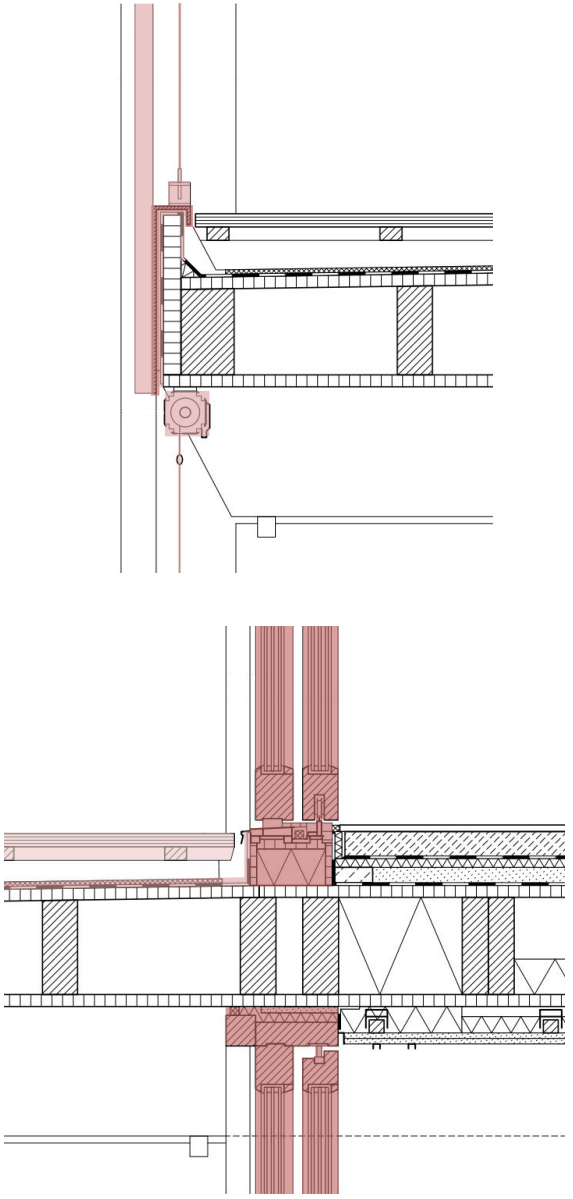
Appendix 10. Impact analysis on Case 2: Pile up Giesshübel (facade panel assembles). (self made)

Layers			Element Names		1	5	2	3	4	20	7	6	8	9	11	10	12	13	17	16	15	14	19	24	18	31	28	21	23	22	25	26	27	29	30	
			Existing concrete storeys and foundation	1		1	1																													
			Steel beams (structural transition)	5	1		1	1	1																												
		STRUCTURE	Extended concrete cores (lifts and stairwells)	2	1	1		1	1								1							1				1	1							
			Glulam timber structural frame (beams and supports)	3		1	1		1							1	1	1						1				1								
			Timber box ceiling with three-layer panel cladding	4		1	1	1		1		1	1	1	1		1	1		1		1	1	1	1			1	1							
		SERVICES	Drainage and pipes	20					1					1	1						1	1	1		1			1	1	1		1	1	1		
			Steel railing	7								1																								
			Facade panel assemblies	6					1		1		1	1	1																						
			Sun blinds	8					1			1		1																							
		SKIN (balcony)	Balcony timber floor	9					1	1		1	1		1	1																				ROUND 3
			Balcony water-proofing layer	11					1	1		1		1			1	1																		ROUND 2
			Balcony partitions	10				1						1				1																		ROUND 4
			Timber sliding doors	12			1	1	1						1			1																		ROUND 1
			Exterior walls (timber stud+insulation+plasterboard)	13				1	1						1	1	1		1																	
			Windows	17														1																		
			Parapet wall	16					1													1														
		SKIN (roof)	Extensive vegetation (roof)	15						1												1														
			Roof finishes and insulation	14					1	1											1	1		1												
		SERVICES	Ventilation system	19					1														1		1				1							
			Ceiling finishes	24			1	1	1	1														1		1	1		1							
		SERVICES	Electrical cables	18					1																1		1	1	1							
	SPACE PLAN		Lighting	31																					1	1									
			Integrated kitchen cabinets	28						1																1			1							
			Partition walls (timber stud+insulation+plasterboard)	21			1	1	1	1													1	1	1		1		1	1	1	1	1	1		
			Flooring finishes	23			1		1	1																		1		1	1	1	1		1	
			Doors (interior)	22																								1	1							
STUFF			Bathroom pods	25						1																		1	1							
			Toilet fixtures	26						1																		1	1							
			Cabinet with sink (toilet)	27						1																		1	1							
			Built-in wardrobe	29																								1								
			Furnitures	30																									1							

Appendix 11. Impact analysis on Case 2: Pile up Giesshübel (timber sliding doors). (self made)



Appendix 12. Details of the facade of Case 1.
Analysis on curtain walls (up) and larch facade panel (down).
(self analysed on drawings from Sandra, H., 2022)



Appendix 13. Details of the balcony of Case 2.
Analysis on facade panel assembles (up) and timber sliding doors (down).
(self analysed on drawings from Kaufmann, H., Krötsch, S. & Winter, S., 2018)

Layers			Element Names		1	2	3	9	10	4	12	5	6	7	8	11	15	16	14	24	23	18	13	17	31	22	20	21	19	27	25	26	28	29	30	
		STRUCTURE	Concrete foundation	1		1	1																													
			Concrete core with staircase	2	1		1												1	1	1	1		1	1		1	1	1	1		1			1	
			Glulam timber structural frame	3	1	1		1		1		1	1	1					1		1			1			1	1							
		SKIN (facade)	Larch lesene	9			1		1	1																										
			Larch mullion with sheet metal coping	10				1		1																										
			Larch facade panels	4			1	1	1		1	1																								
			Window blinds (outdoor)	12						1			1																							
			Insulation and sealant (exterior wall)	5			1			1				1																						
			Curtain walls (triple glazing in spruce frame)	6			1				1				1	1	1																			
			CLT walls (exterior)	7			1					1	1		1																					
			Doors (exterior)	8									1	1																						
			Window blinds (indoor)	11									1																							
		SKIN (roof)	Insulation and sealant (roof)	15														1	1	1																
			Aluminum coping (roof)	16													1																			
	SPACE PLAN		CLT ceiling (roof)	14		1	1										1				1			1	1										
			Doors (interior)	24		1															1							1								
			Partition walls (timber frame and various panels)	23		1	1												1	1	1	1					1	1								
		SERVICES	Ventilation system	18		1															1															
			Spruce window seats	13																			1	1				1								ROUND 2
		SERVICES	Electrical wiring and data cables	17		1	1												1				1		1		1						1		ROUND 1
			Lighting	31		1													1					1		1	1								
			Acoustic ceiling	22																					1		1								
			CLT floor panels	20		1	1														1			1	1	1		1							
			Flooring finishes and insulation	21		1	1													1	1		1				1		1	1	1			1		
STUFF		SERVICES	Water pipes	19		1																						1		1	1	1				
			Kitchen cabinets and sinks	27		1																						1	1			1	1			
			Toilet fixtures	25																								1	1							
			Plumbing accessories (faucet, pipes)	26		1																							1	1						
			Appliances	28																			1							1				1		
			Furnitures	29																							1						1			
			Hanging greenery	30		1																														

Appendix 14. Impact analysis on Case 1: Library and Seminar Centre (electrical wiring and cables). (self made)

Layers			Element Names		1	2	3	9	10	4	12	5	6	7	8	11	15	16	14	24	23	18	13	17	31	22	20	21	19	27	25	26	28	29	30	
		STRUCTURE	Concrete foundation	1		1	1																													
			Concrete core with staircase	2	1		1												1	1	1	1		1	1		1	1	1	1		1			1	
			Glulam timber structural frame	3	1	1		1		1		1	1	1					1		1			1			1	1							
		SKIN (facade)	Larch lesene	9			1		1	1																										
			Larch mullion with sheet metal coping	10				1		1																										
			Larch facade panels	4			1	1	1		1	1																								
			Window blinds (outdoor)	12						1			1																							
		SKIN (facade)	Insulation and sealant (exterior wall)	5			1			1				1																						
			Curtain walls (triple glazing in spruce frame)	6			1				1				1	1	1																			
			CLT walls (exterior)	7			1					1	1		1																					
			Doors (exterior)	8									1	1																						
			Window blinds (indoor)	11									1																							
		SKIN (roof)	Insulation and sealant (roof)	15														1	1	1																
			Aluminum coping (roof)	16													1																			
	SPACE PLAN		CLT ceiling (roof)	14		1	1										1				1			1	1										
			Doors (interior)	24		1															1							1								ROUND 4
			Partition walls (timber frame and various panels)	23		1	1												1	1	1	1					1	1								ROUND 3
		SERVICES	Ventilation system	18		1															1															
			Spruce window seats	13																			1	1				1								ROUND 3
		SERVICES	Electrical wiring and data cables	17		1	1												1				1		1		1						1		ROUND 4
			Lighting	31		1													1					1		1	1								
			Acoustic ceiling	22																					1		1								
			CLT floor panels	20		1	1														1			1	1	1		1							
			Flooring finishes and insulation	21		1	1													1	1		1				1		1	1	1			1		ROUND 2
		SERVICES	Water pipes	19		1																						1		1	1	1				ROUND 1
			Kitchen cabinets and sinks	27		1																						1	1			1	1			
STUFF			Toilet fixtures	25																								1	1							ROUND 2
			Plumbing accessories (faucet, pipes)	26		1																							1	1						
			Appliances	28																			1							1				1		ROUND 3
			Furnitures	29																							1						1			
			Hanging greenery	30		1																														

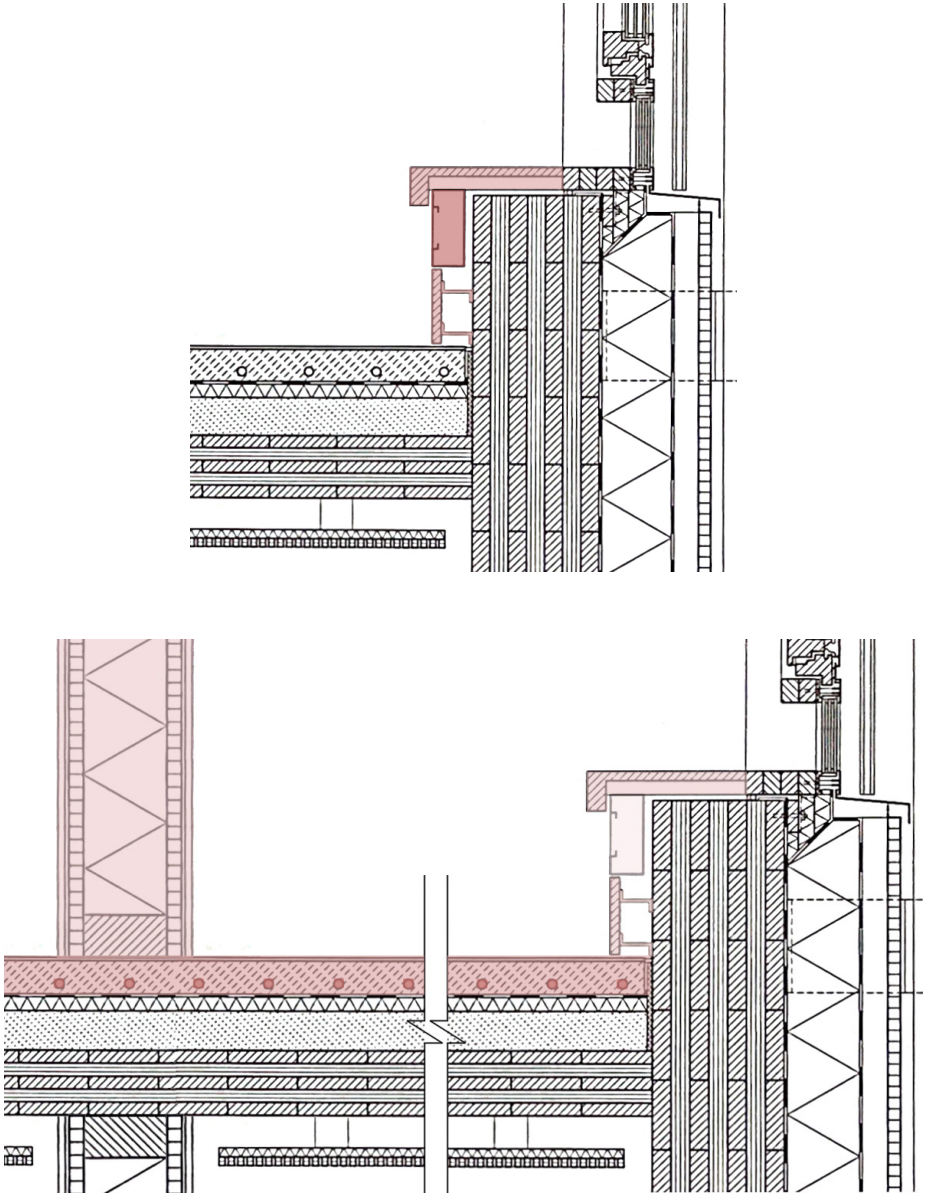
Appendix 15. Impact analysis on Case 1: Library and Seminar Centre (water pipes). (self made)

Layers			Element Names		1	5	2	3	4	20	7	6	8	9	11	10	12	13	17	16	15	14	19	24	18	31	28	21	23	22	25	26	27	29	30	
			Existing concrete storeys and foundation	1		1	1																													
			Steel beams (structural transition)	5	1		1	1	1																											
		STRUCTURE	Extended concrete cores (lifts and stairwells)	2	1	1		1	1								1							1				1	1							
			Glulam timber structural frame (beams and supports)	3		1	1		1							1	1	1						1				1								
			Timber box ceiling with three-layer panel cladding	4		1	1	1		1		1	1	1	1		1	1		1		1	1	1	1			1	1							
		SERVICES	Drainage and pipes	20					1					1	1						1	1		1			1	1	1		1	1	1			ROUND 4
			Steel railing	7								1																								
			Facade panel assemblies	6					1		1		1	1	1																					
			Sun blinds	8					1			1		1																						
			Balcony timber floor	9					1	1		1	1		1	1																				
		SKIN (balcony)	Balcony water-proofing layer	11					1	1		1		1			1	1																		
			Balcony partitions	10				1						1				1																		
			Timber sliding doors	12			1	1	1						1			1																		
			Exterior walls (timber stud+insulation+plasterboard)	13				1	1						1	1	1		1																	
			Windows	17														1																		
			Parapet wall	16					1														1													
		SKIN (roof)	Extensive vegetation (roof)	15						1												1													
			Roof finishes and insulation	14					1	1											1	1		1												
		SERVICES	Ventilation system	19					1														1		1				1							ROUND 3
			Ceiling finishes	24			1	1	1	1														1		1	1		1							ROUND 2
		SERVICES	Electrical cables	18					1															1		1	1	1								ROUND 1
	SPACE PLAN		Lighting	31																				1	1											
			Integrated kitchen cabinets	28						1															1			1								ROUND 2
			Partition walls (timber stud+insulation+plasterboard)	21			1	1	1	1													1	1	1		1		1	1	1	1	1	1		
			Flooring finishes	23			1		1	1																		1		1	1	1			1	ROUND 3
			Doors (interior)	22																								1	1							
STUFF			Bathroom pods	25						1																		1	1							
			Toilet fixtures	26						1																		1	1							ROUND 4
			Cabinet with sink (toilet)	27						1																		1	1							
			Built-in wardrobe	29																								1								ROUND 3
			Furnitures	30																									1							ROUND 4

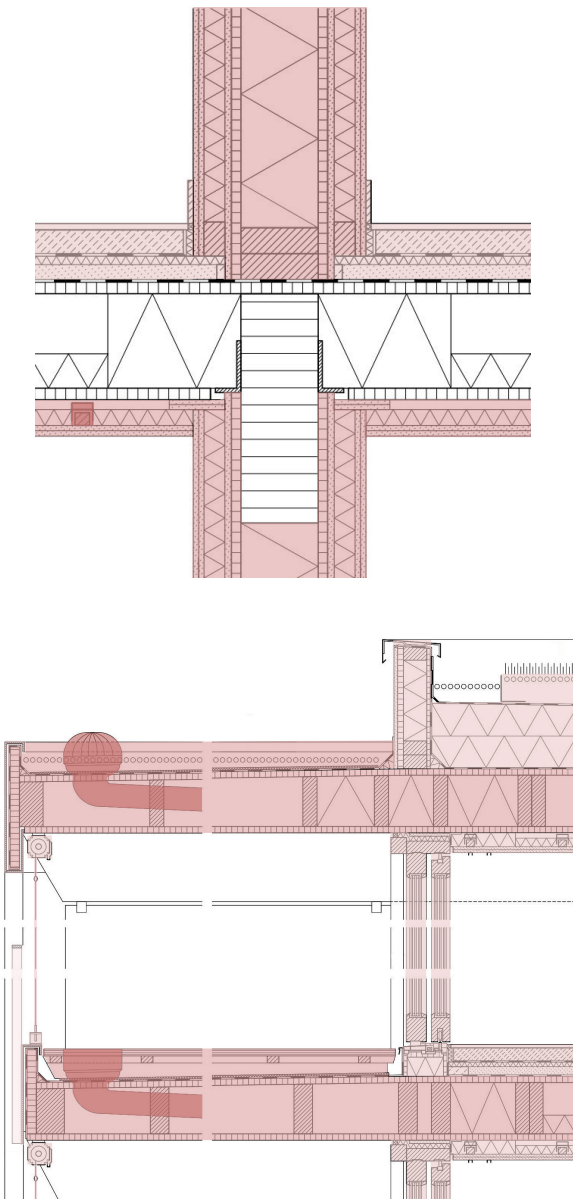
Appendix 16. Impact analysis on Case 2: Pile up Giesshübel (electrical cables). (self made)

Layers			Element Names		1	5	2	3	4	20	7	6	8	9	11	10	12	13	17	16	15	14	19	24	18	31	28	21	23	22	25	26	27	29	30	
			Existing concrete storeys and foundation	1		1	1																													
			Steel beams (structural transition)	5	1		1	1	1																											
		STRUCTURE	Extended concrete cores (lifts and stairwells)	2	1	1		1	1								1							1				1	1							
			Glulam timber structural frame (beams and supports)	3		1	1		1							1	1	1						1				1								
			Timber box ceiling with three-layer panel cladding	4		1	1	1		1		1	1	1	1		1	1		1		1	1	1	1			1	1							ROUND 2
		SERVICES	Drainage and pipes	20					1					1	1						1	1		1			1	1	1		1	1	1			ROUND 1
			Steel railing	7								1																								ROUND 4
			Facade panel assemblies	6					1		1		1	1	1																					ROUND 3
			Sun blinds	8					1			1		1																						
			Balcony timber floor	9					1	1		1	1		1	1																				ROUND 2
		SKIN (balcony)	Balcony water-proofing layer	11					1	1		1		1			1	1																		
			Balcony partitions	10				1						1				1																		
			Timber sliding doors	12			1	1	1						1			1																		ROUND 3
			Exterior walls (timber stud+insulation+plasterboard)	13				1	1						1	1	1		1																	
			Windows	17														1																		ROUND 4
			Parapet wall	16					1														1													ROUND 3
		SKIN (roof)	Extensive vegetation (roof)	15						1												1													ROUND 2
			Roof finishes and insulation	14					1	1											1	1		1												
		SERVICES	Ventilation system	19					1														1		1				1	1						ROUND 3
			Ceiling finishes	24			1	1	1	1														1		1	1		1							ROUND 2
		SERVICES	Electrical cables	18					1															1		1	1	1								
	SPACE PLAN		Lighting	31																				1	1											ROUND 3
			Integrated kitchen cabinets	28						1															1			1								
			Partition walls (timber stud+insulation+plasterboard)	21			1	1	1	1													1	1	1		1		1	1	1	1	1	1		ROUND 2
			Flooring finishes	23			1		1	1													1					1		1	1	1			1	ROUND 3
			Doors (interior)	22																								1	1							
STUFF			Bathroom pods	25						1																		1	1							
			Toilet fixtures	26						1																		1	1							ROUND 2
			Cabinet with sink (toilet)	27						1																		1	1							
			Built-in wardrobe	29																								1								ROUND 3
			Furnitures	30																									1							ROUND 4

Appendix 17. Impact analysis on Case 2: Pile up Giesshübel (drainage and water pipes). (self made)

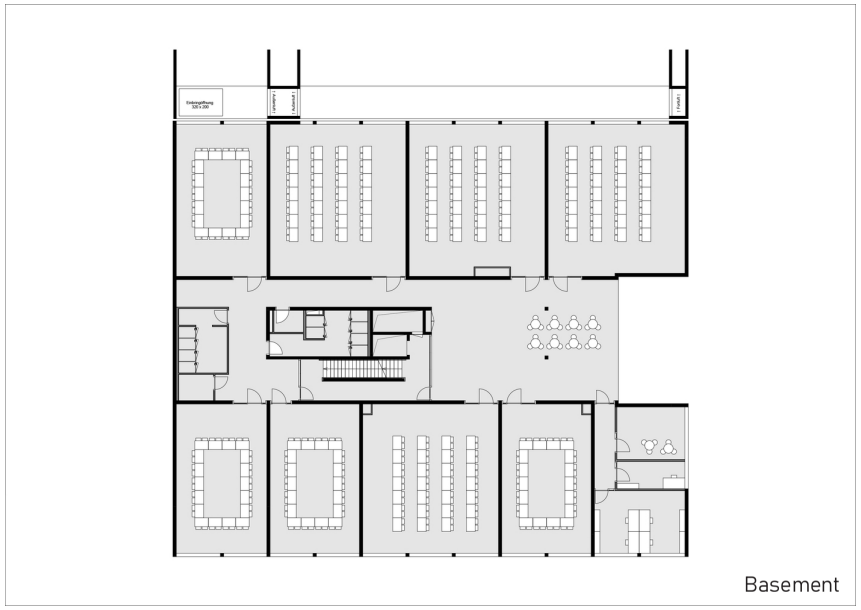


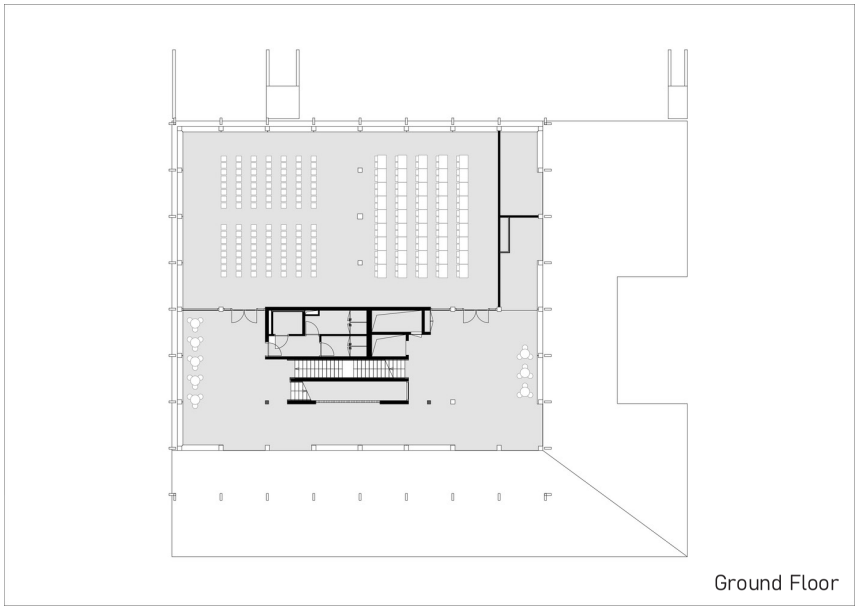
Appendix 18. Details of Case 1.
Analysis on electrical cables (up) and water pipes (down).
(self analysed on drawings from Sandra, H., 2022)

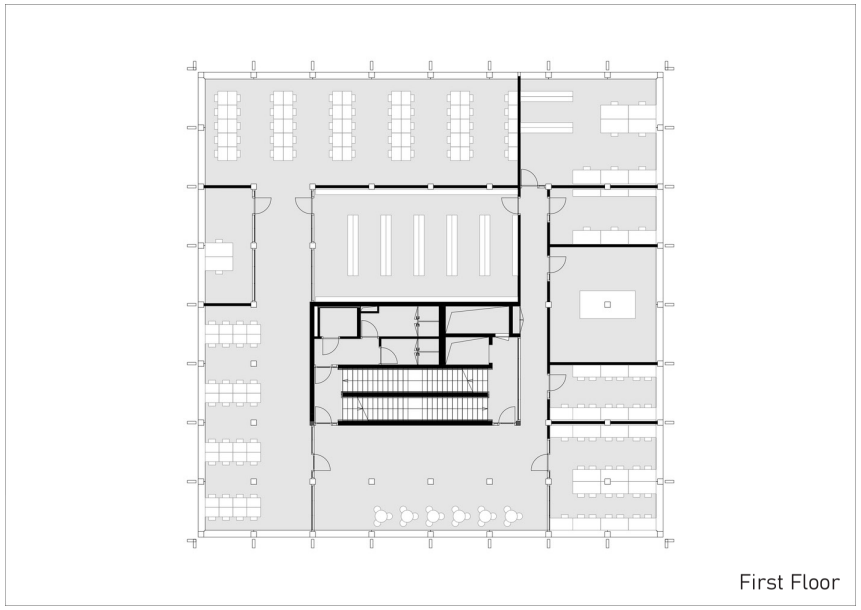


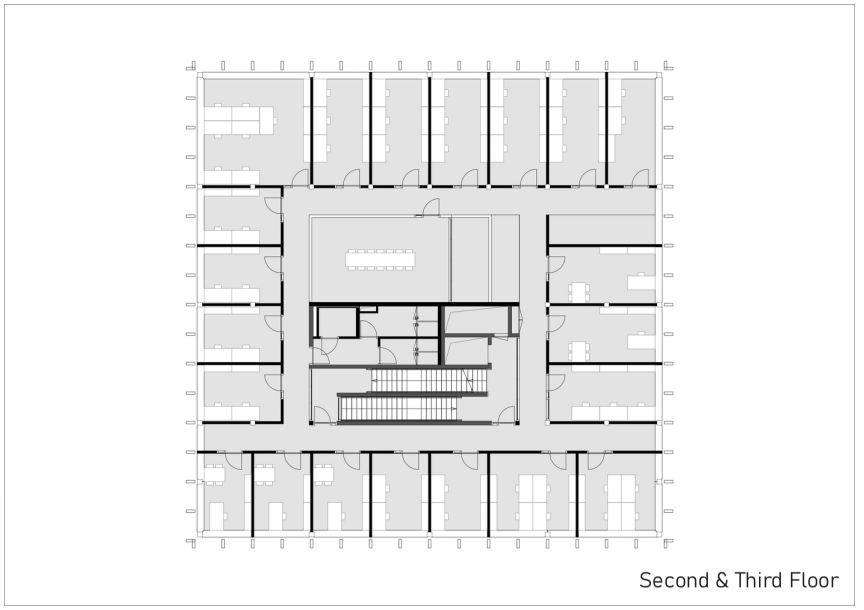
Appendix 19. Details of Case 2.
Analysis on electrical cables (up) and drainage & water pipes (down).
(self analysed on drawings from Kaufmann, H., Krötsch, S. & Winter, S., 2018)

APPENDIX. MATERIALS OF CASE 1

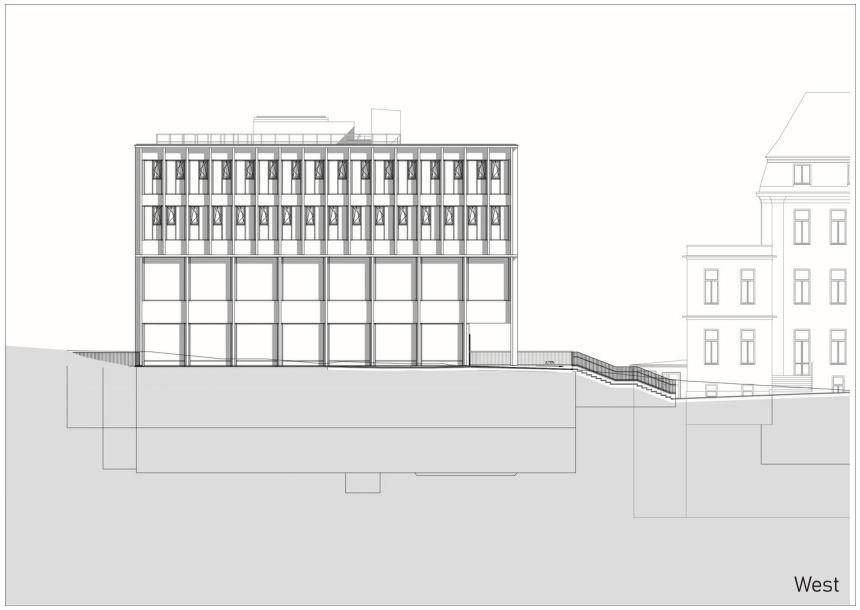


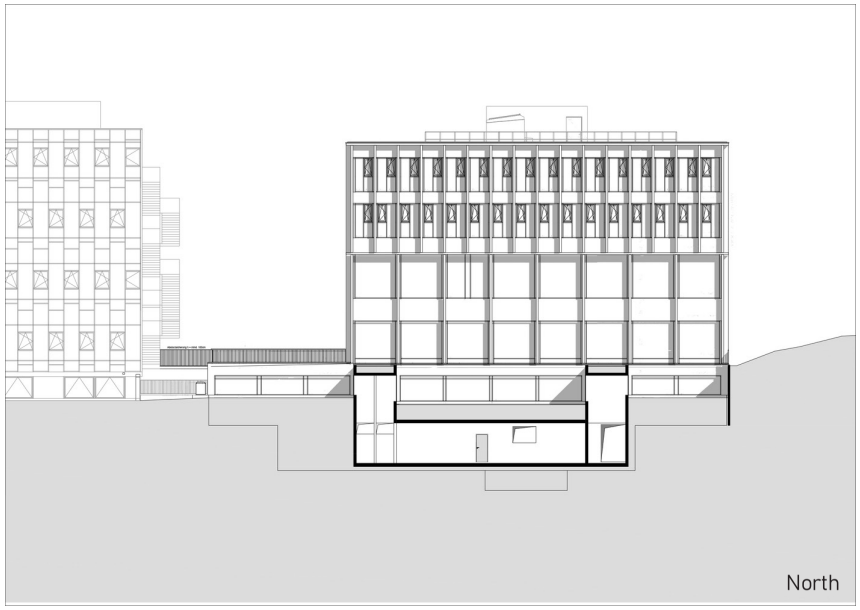


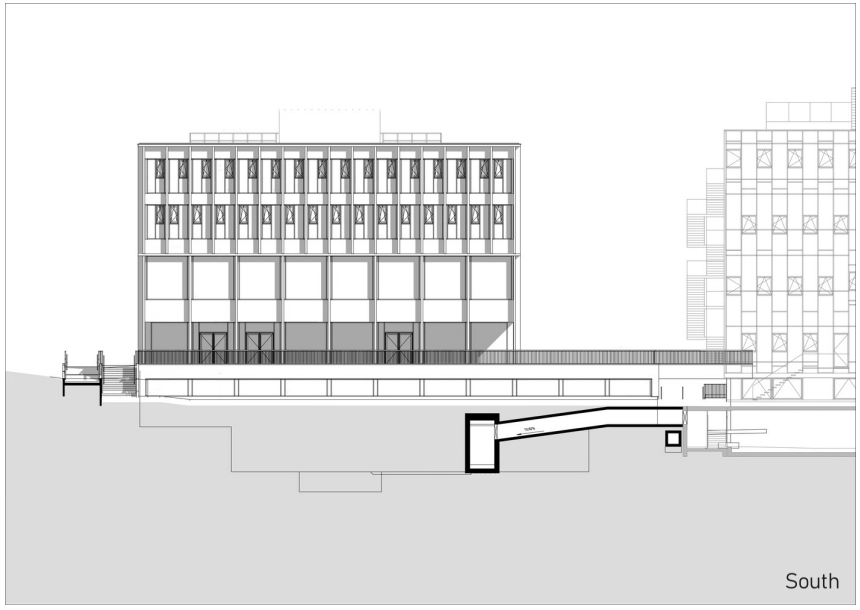




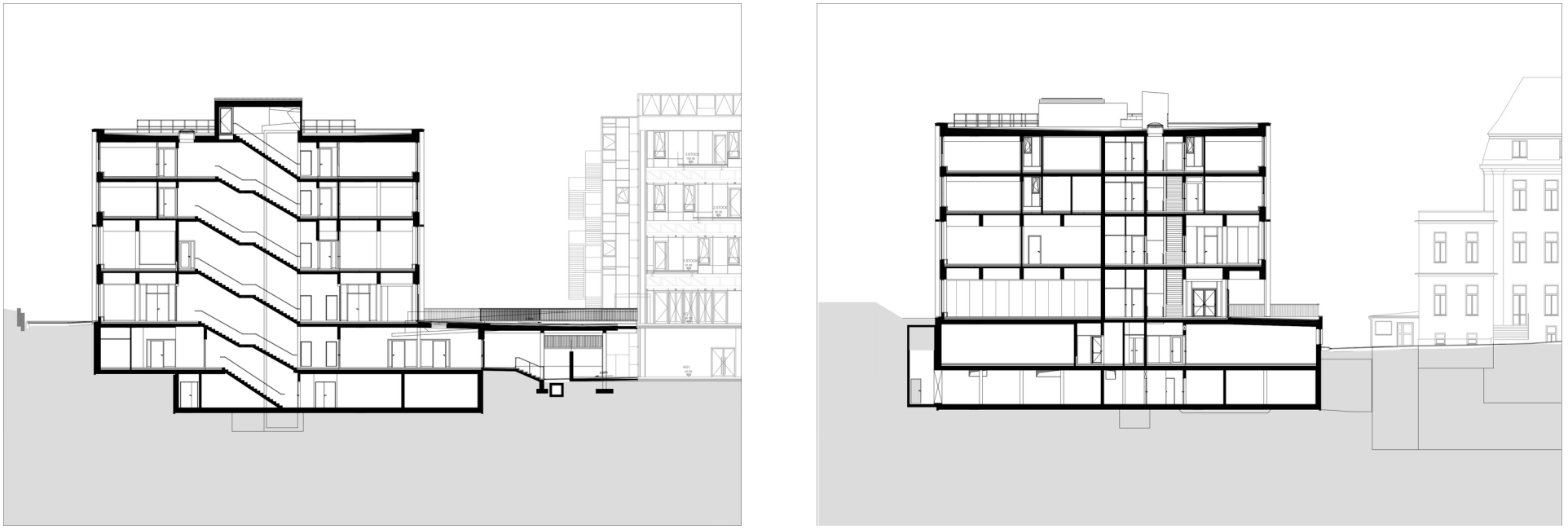
Appendix 20. Floor plans of Case 1: Library and Seminar Centre. (SWAP Architekten & DELTA, 2020)



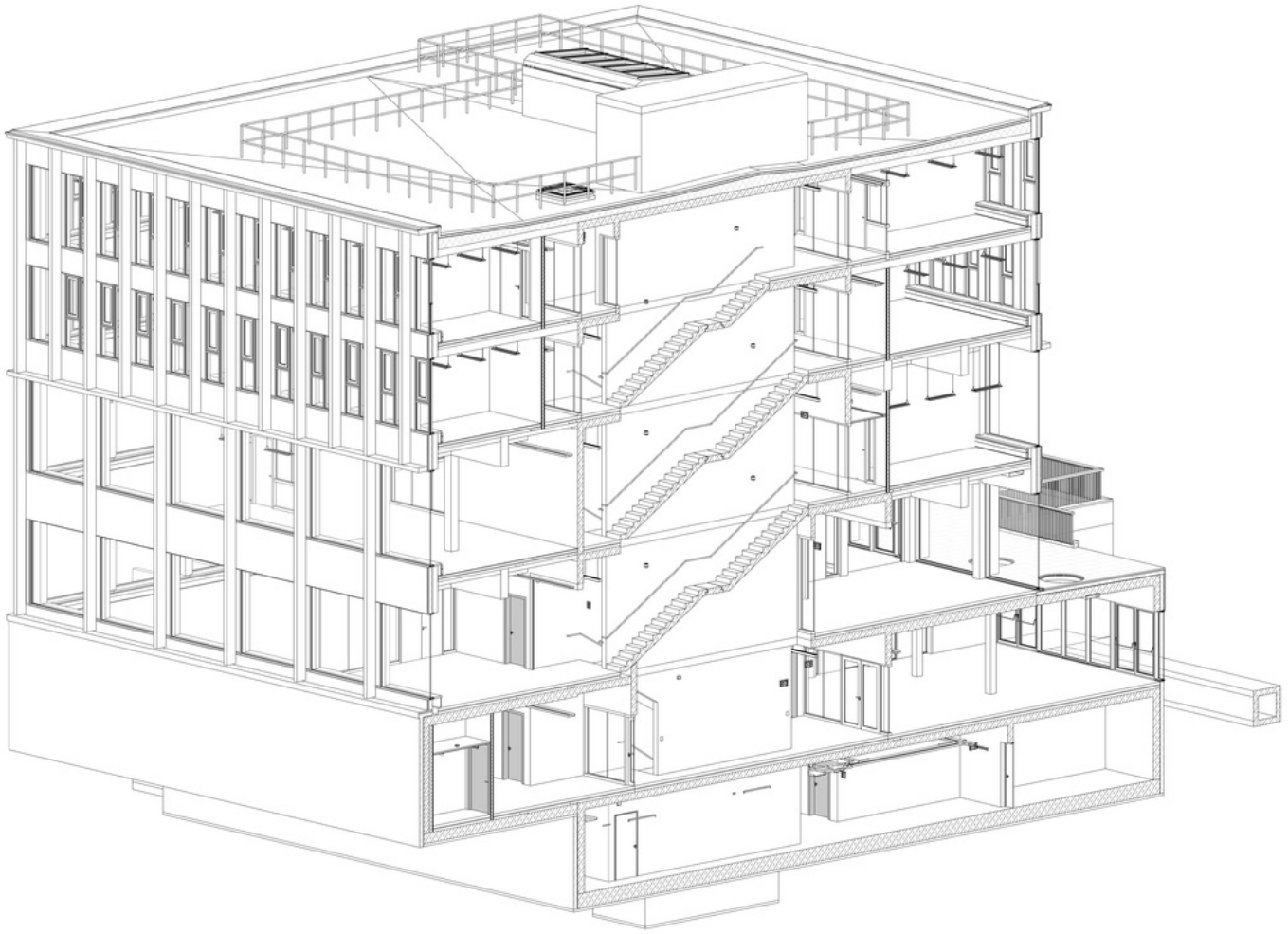




Appendix 21. Elevations of Case 1: Library and Seminar Centre. (SWAP Architekten & DELTA, 2020)

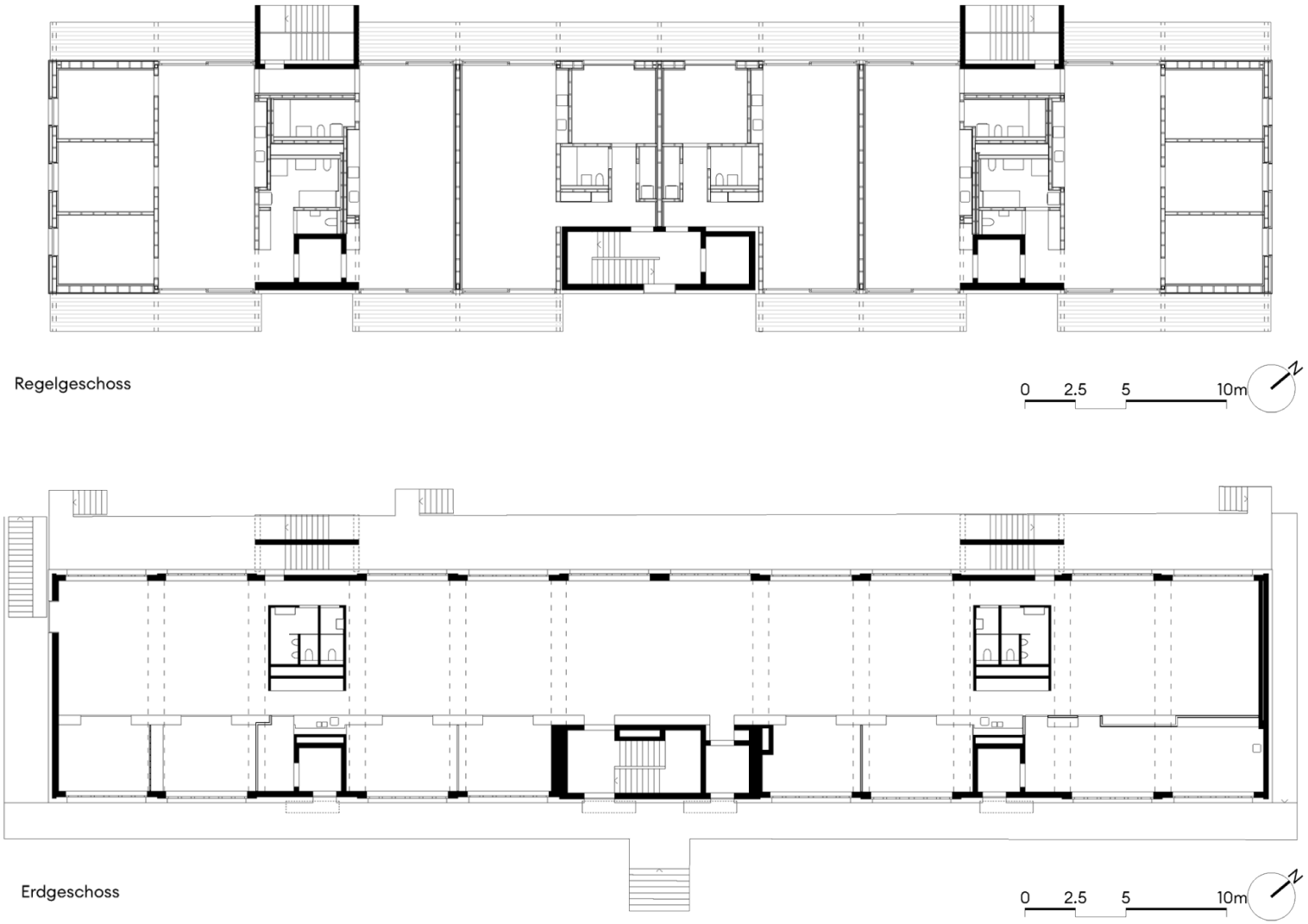


Appendix 22. Sections of Case 1: Library and Seminar Centre. (SWAP Architekten & DELTA, 2020)

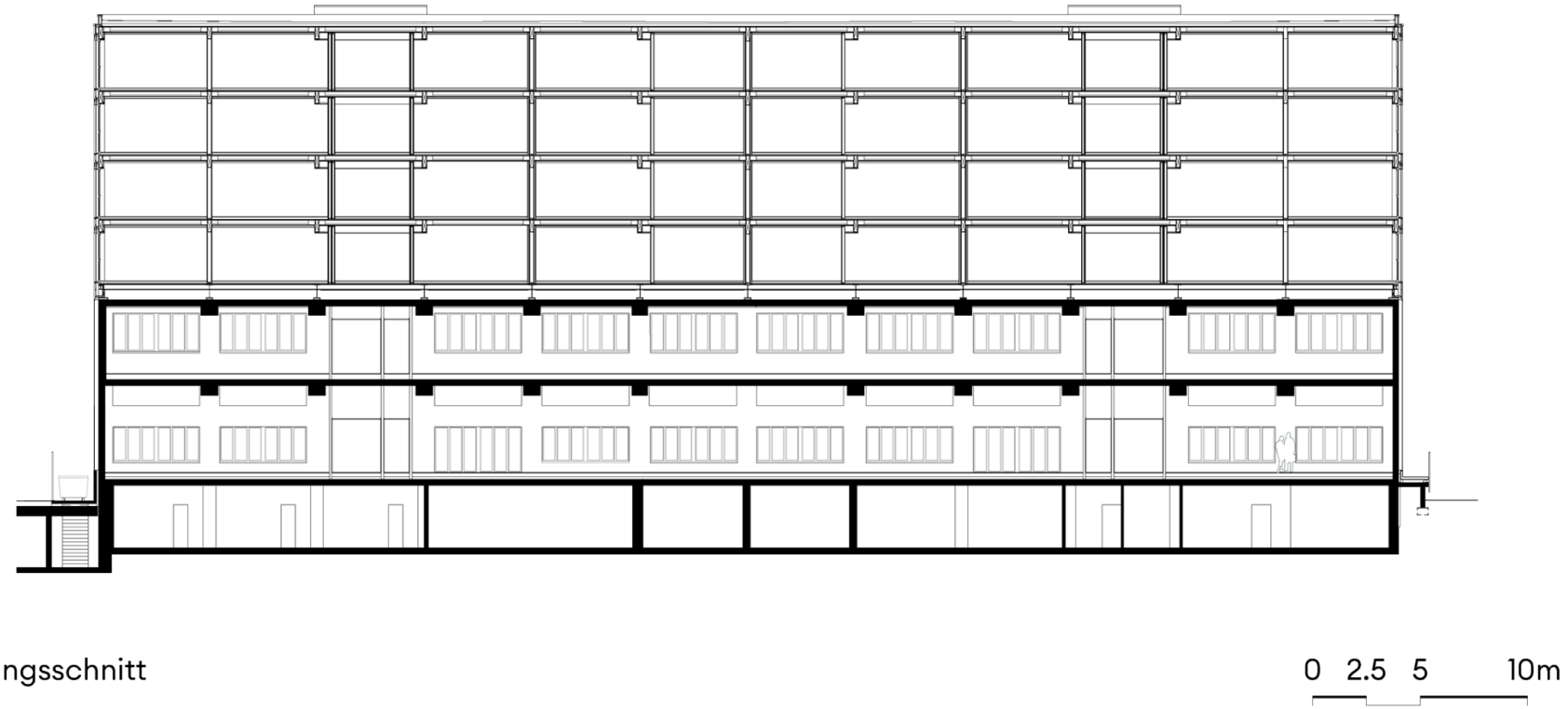


Appendix 23. Axonometric section of Case 1: Library and Seminar Centre. (SWAP Architekten & DELTA, 2020)

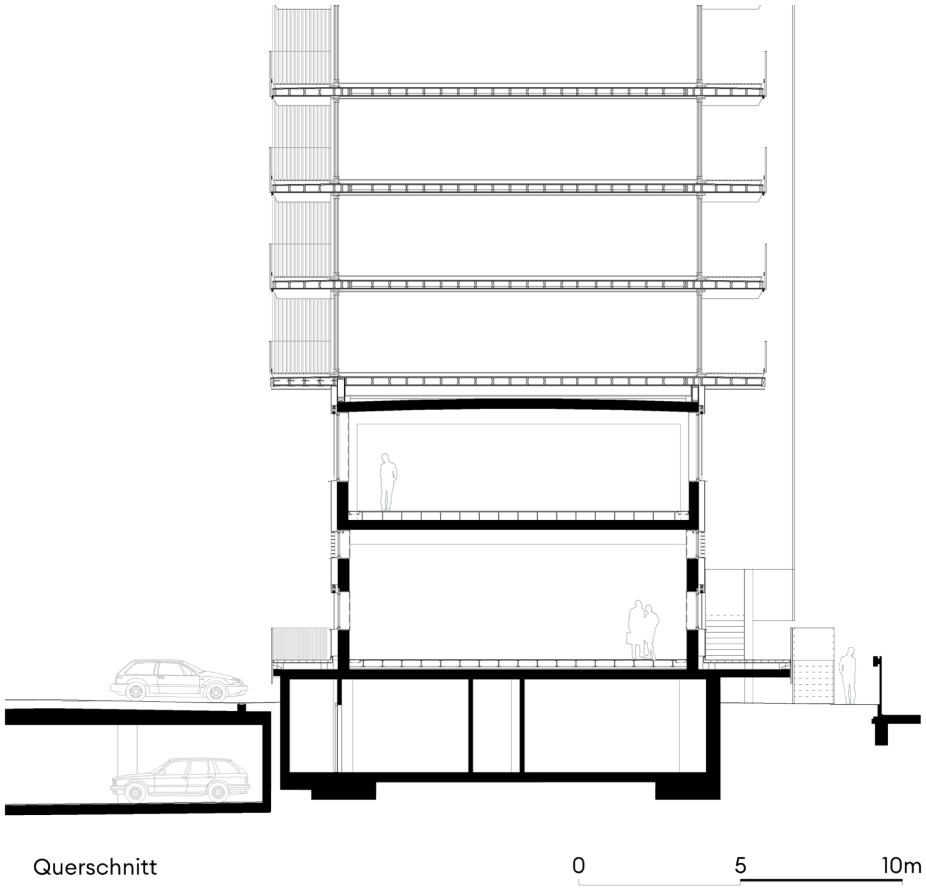
APPENDIX. MATERIALS OF CASE 2



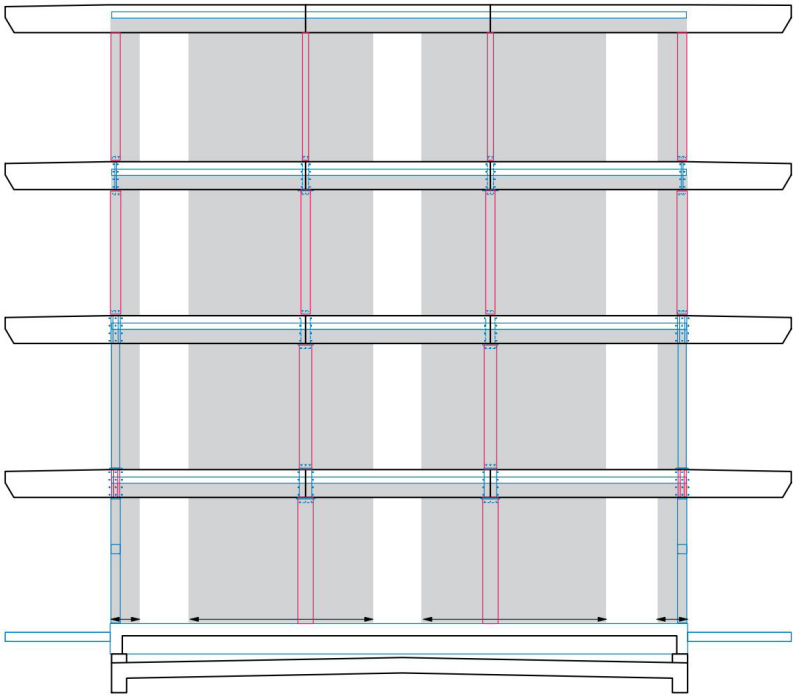
Appendix 24. Plans of Case 2: Pile up Giesshübel. (Oxid Architektur, 2013)



Appendix 25. Section of Case 2: Pile up Giesshübel. (Oxid Architektur, 2013)



Appendix 26. Section of Case 2: Pile up Giesshübel.
(Oxid Architektur, 2013)



Appendix 27. Static load transfer system.
(Kaufmann, H., Krötsch, S. & Winter, S., 2018)