ADAPTABLE TIMBER BUILDING

From Student Housing towards a Mix-use Community with a Low Cost

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KEYWORDS

Adaptability, Shearing layers, Detachability, Timber construction, Timber joinery, Student housing, Mix-use community, Convertibility, Expandability, Low-cost

DEFINITION OF TERMS

Adaptability: The capacity of buildings to accommodate substantial change. (IEA Annex 31, 2001)

The shearing layers: It envisions a building as a set of 'shearing' layers that change at different rates.

Detachability: The independence of building elements by having separable joints.

Mass timber: Mass timber uses state-of-the-art technology to glue, nail, or dowel wood products together in layers. The results are large structural panels, posts, and beams. These exceptionally strong and versatile products are known as mass timber.

Timber joinery: A traditional post and beam wood construction technique used to connect wood members without the use of metal fasteners, which requires that the ends of timbers are carved out so that they fit together like puzzle pieces.

Convertibility: The ability to change the function of a building through a certain amount of construction work.

Expandability: The ability to expand the scale of a building horizontally or vertically.

CONTENTS

INTRODUCTION

As climate change and resource scarcities become urgent issues around the world, there has been an increasing focus on strategies and techniques that help to achieve a more sustainable future.

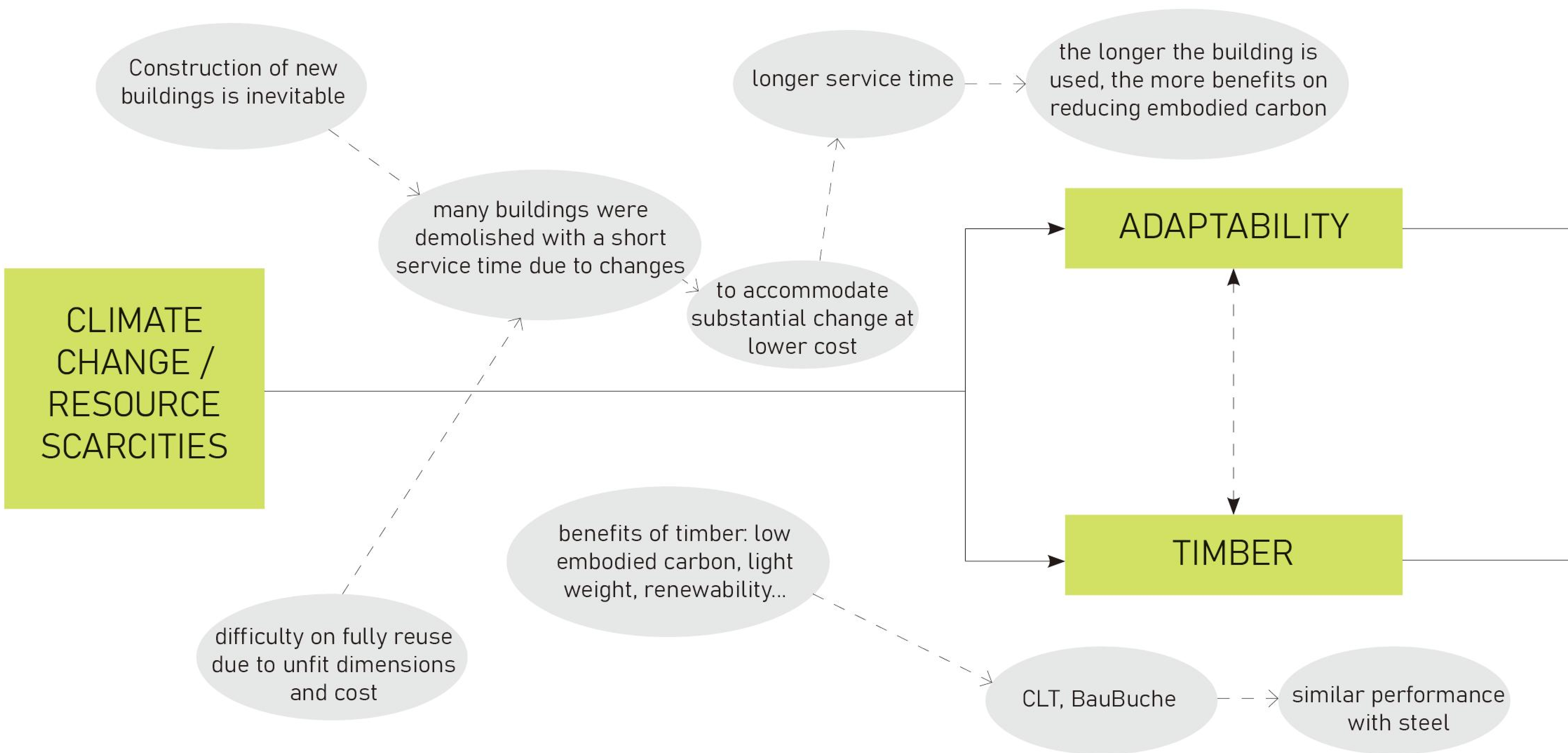
ADAPTABILITY

On one hand, the concept of adaptability has gradually come into people's vision. During a building's lifetime, change is inevitable, both in the social, economic, physical surroundings, and in the needs of occupants. 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 key 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 greater difficulty and cost of adaptation. Therefore, the high independency of layers can greatly help to achieve a building's adaptability. In the book Adaptable architecture: theory and practice, Schmidt and Austin expand Brand's model to cover a broader interpretation by adding two additional layers - social and surroundings. They claim that buildings cannot be isolated from their surrounding context and that the social perspectives of users, occupants and community need to be included in the model. The two additional layers can be subdivided into 7 sub-layers which are buildings, natural elements, landmarks, public space, service infrastructure, street furniture and transportation. The expanded model shows that adaptability is context-related.

TIMBER

On the other hand, timber has caught a renewed interest as a structural material, due to its features of low embodied carbon, light weight, and renewability in principle. Engineered timber products, such as cross-laminated timber (CLT) and hardwood laminated timber (BauBuche) which have similar performance to steel, promote the development of timber structures in multi-storey buildings. Timber joinery is a traditional technique used to connect wood members without the use of metal fasteners. The use of timber joinery as connections faded with the development of steel connections. However, two recent developments offer the opportunity to revive this kind of technics: 1) the increasing desire to reduce embodied carbon in buildings by replacing more components with timber as a low-carbon material; 2) recent digital fabrication technology enables the precise milling of complex geometries and can be an alternative to previous labour-intensive handiwork. (Fang, 2020)

Connected to the two themes, an adaptable timber building has a longer service time, and then the carbon can be restored in timber materials for longer, making more environmental benefits.



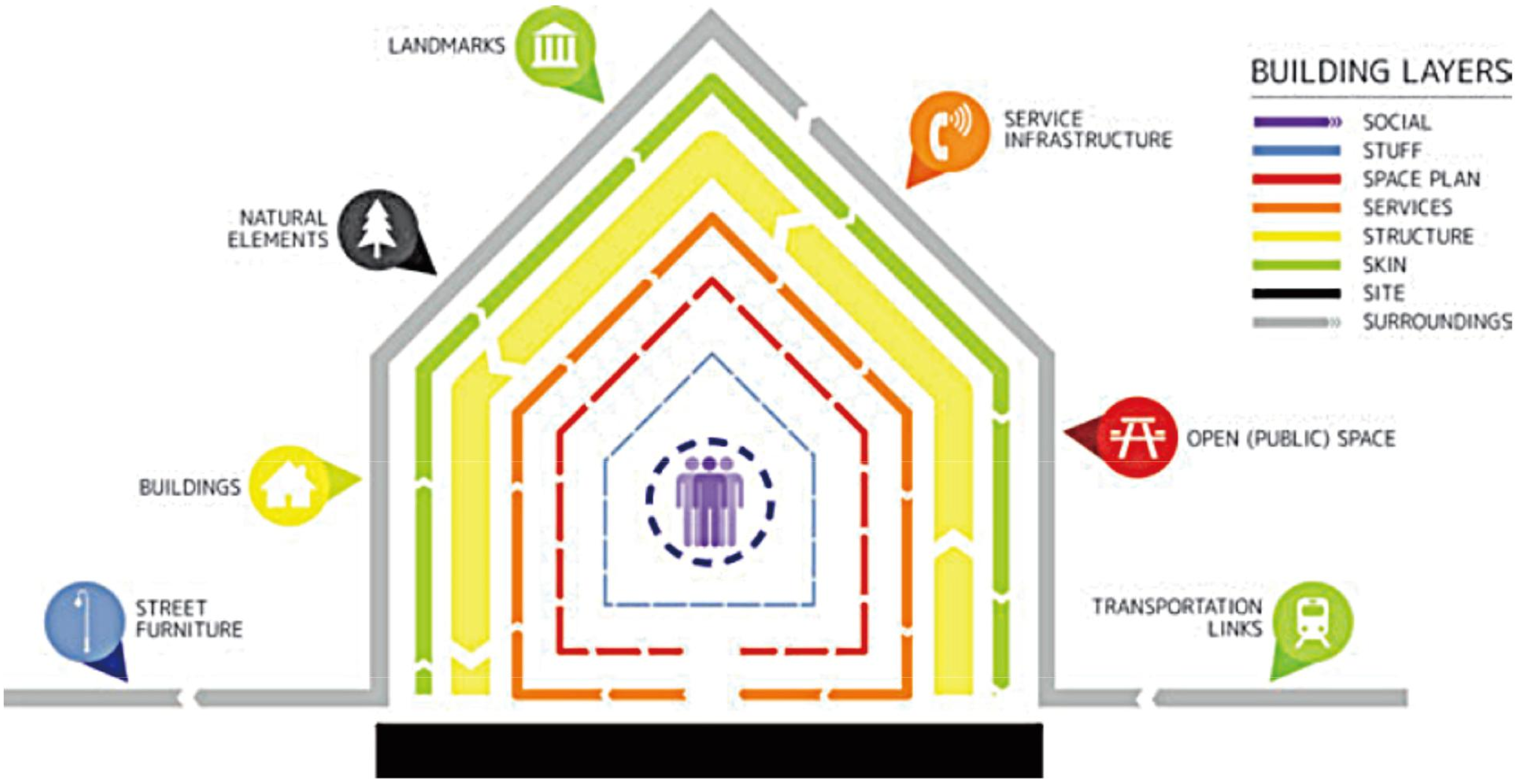


Figure 1. The expanded model of shearing layers. (Schmidt, R., & Austin, S. A. ,2016.)

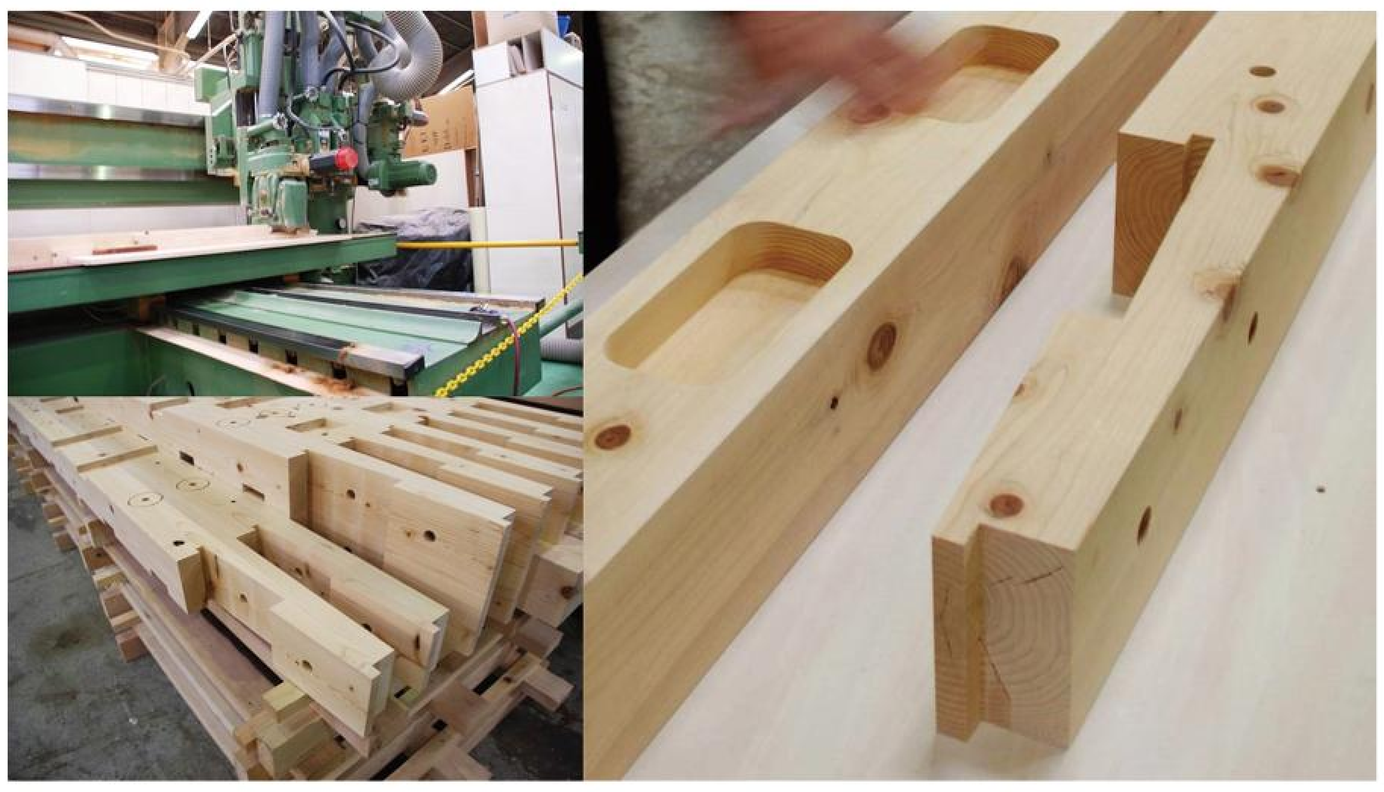


Figure 2. Digital fabrication of timber (Mokuzai Kaikan)

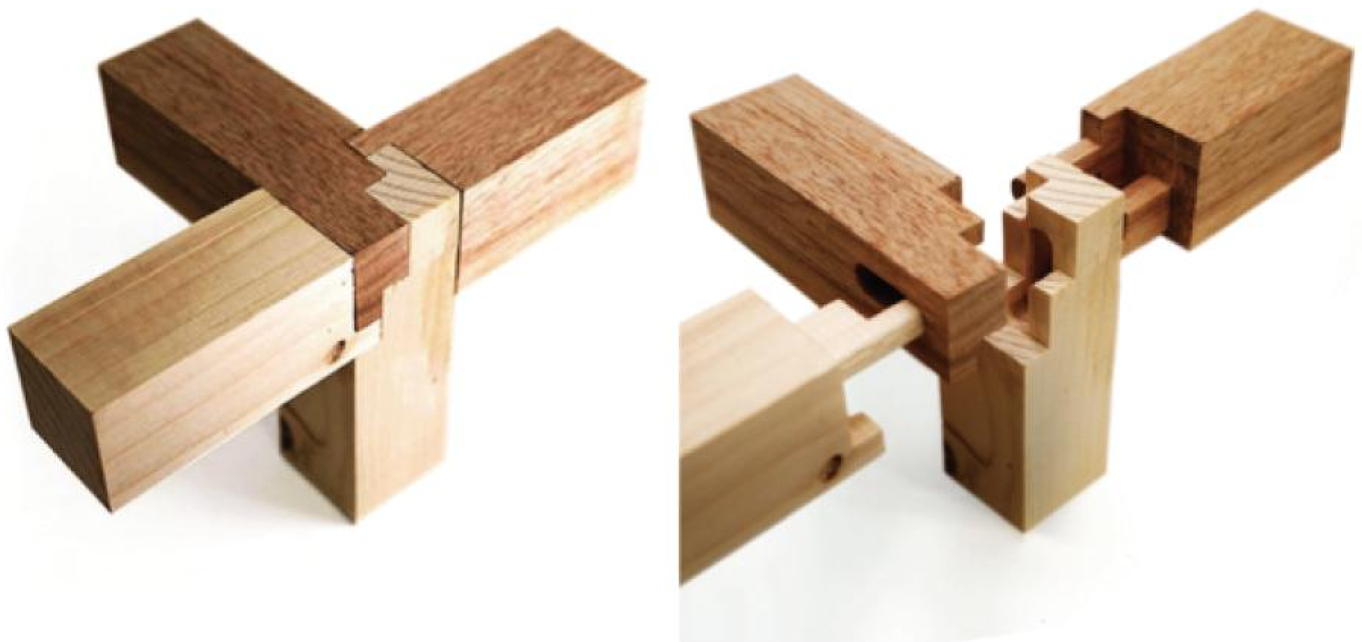


Figure 3. Digital fabrication of timber joinery (Tsugite)

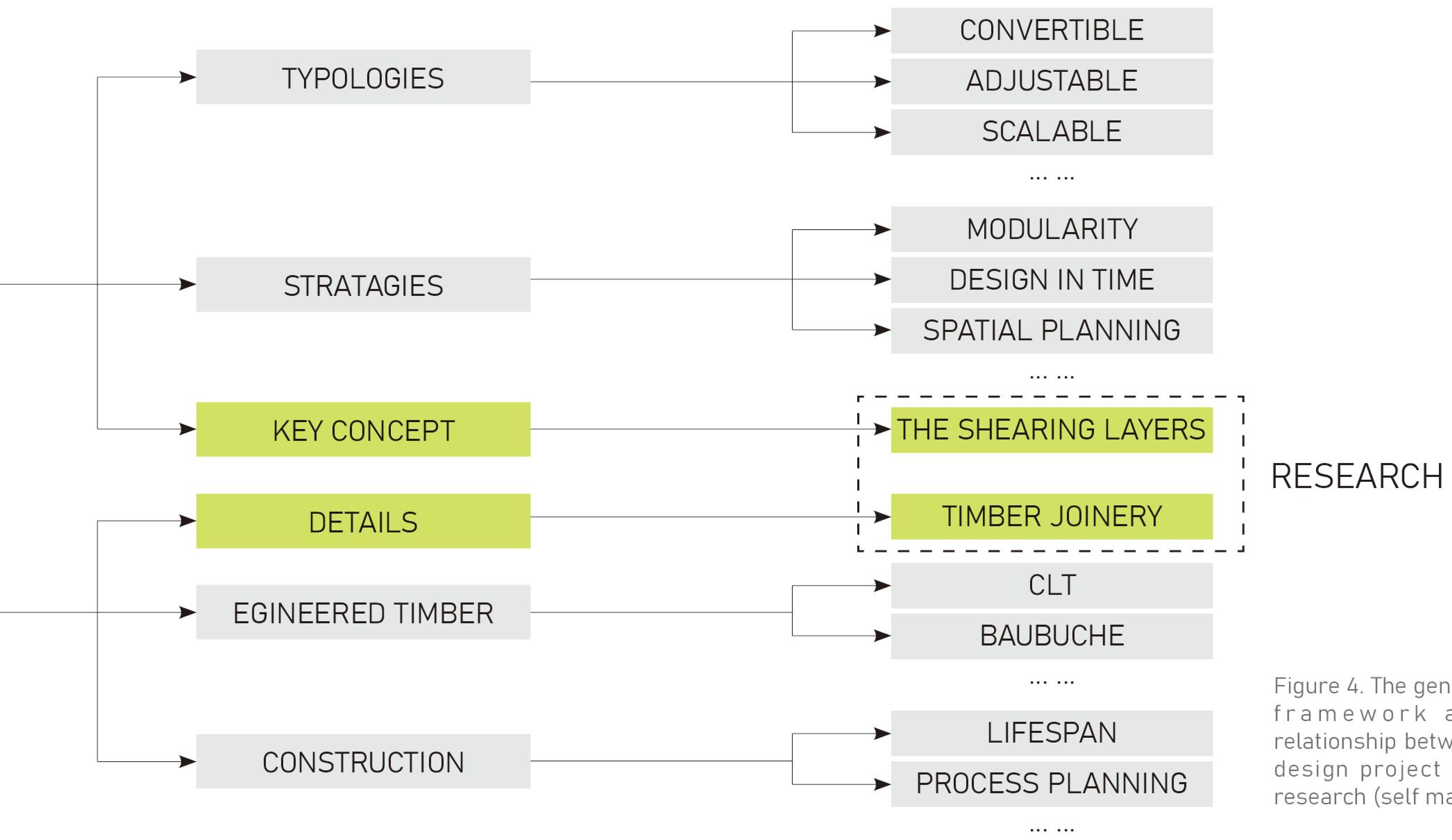


Figure 4. The general framework and relationship between design project and research (self made)

PROBLEM STATEMENT & CONTEXT

When considering a building's adaptability, it is very important to find out what is likely to change in the specific context and then adopt corresponding strategies to improve the ability to respond to these changes. The site I choose is on Heertjeslaan, TU Delft Campus South. The main problem of the site is the contradiction between social needs and the campus development plan. On one hand, the student housing corporation Duwo is planning to build student housing on the site, which can help ease the student housing shortage in Delft. On the other hand, TU Delft is planning to develop the Campus South area into an innovative hub, providing more places for educational institutes and tech companies. According to the campus development plan, the site, highlighted in the map, is a part of the business & research zone and will be developed in the second phase which is about 15 years later. Therefore, TU Delft claims that student housing can only serve for 15 years until the arrival of tech companies, while Duwo desires to have a longer time because of better economic benefits. In addition, the demand for student housing is unlikely to reduce but to keep increasing in the future. It is unreasonable to demolish the existing student housing.

OBJECTIVE

How to deal with the problem? In fact, these two things can co-exist. The campus south can become an innovation hub as planning, and at the same time, takes the responsibility of easing the student housing shortage. The graduation project intends to design an adaptable timber building which is convertible and expandable from student housing towards a mix-use community with a low cost. Figure 6 shows the future transformation scheme. In the first 15 years, the project will be affordable and livable student housing. It will contain at least 660 student housing units and other communal spaces for communication and activities. After that, the site will be developed into a research & business area as a part of the 'innovative hub', accepting tech companies to settle in. The building can be partly transformed into offices, labs, and studios for tech companies, and can gradually expand if needed. Finally, the building might develop into a mix-use community with both residential, research and business program. For more details, Figure 7 analyses the possible future changes of the site, including the types, likelihood, possible happening time, and the degree of influence on the project. It can help me identify which changes are more important to my design, when to consider the changes, and what adaptability types the changes lead to. In this way, I can find suitable strategies to achieve adaptability.

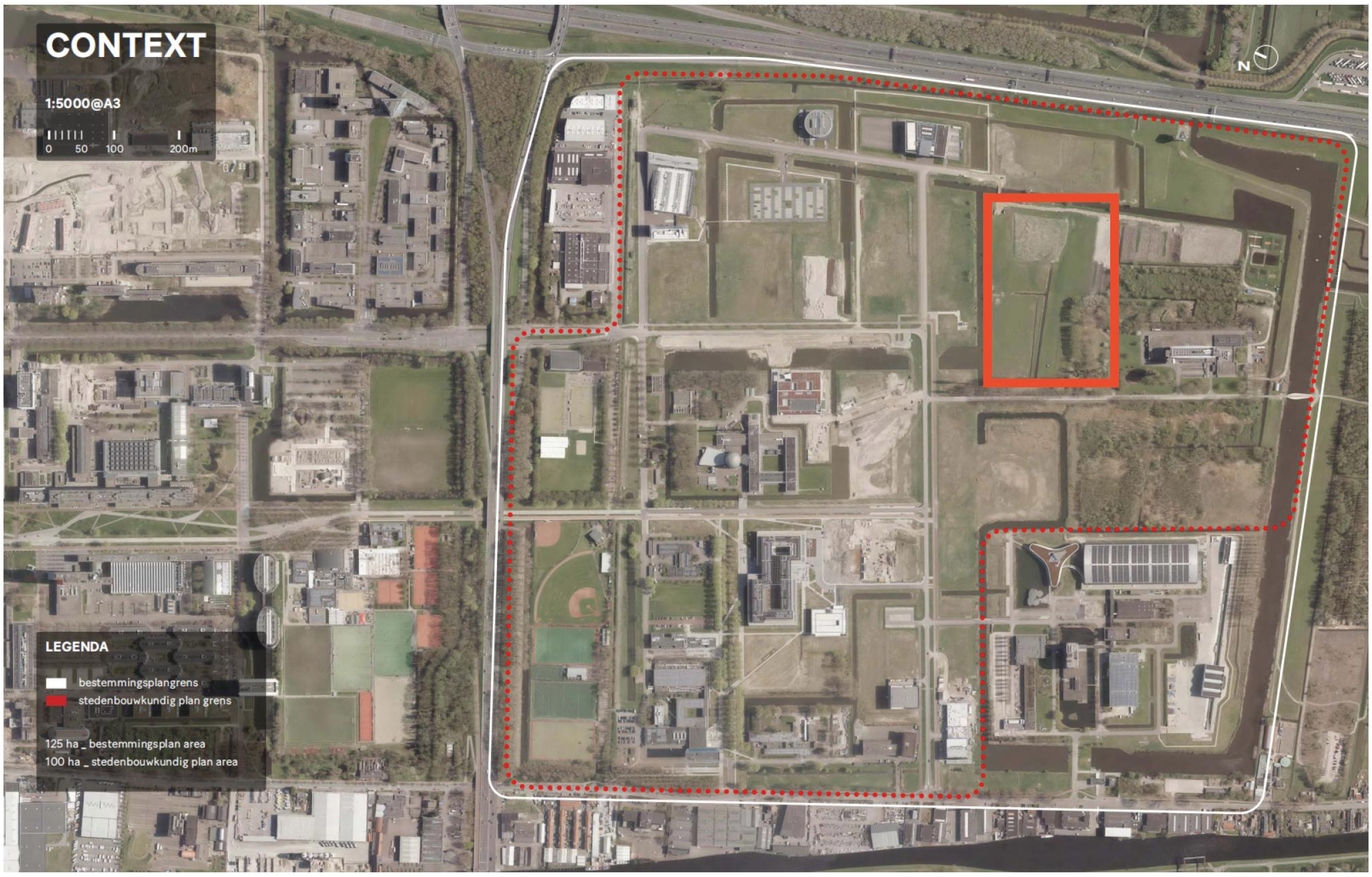


Figure 5. The site location (revised from TU Delft Campus South development plan)

OVERALL DESIGN QUESTION

How can we design an adaptable timber building that is convertible and expandable from student housing towards a mix-use community with a low cost?

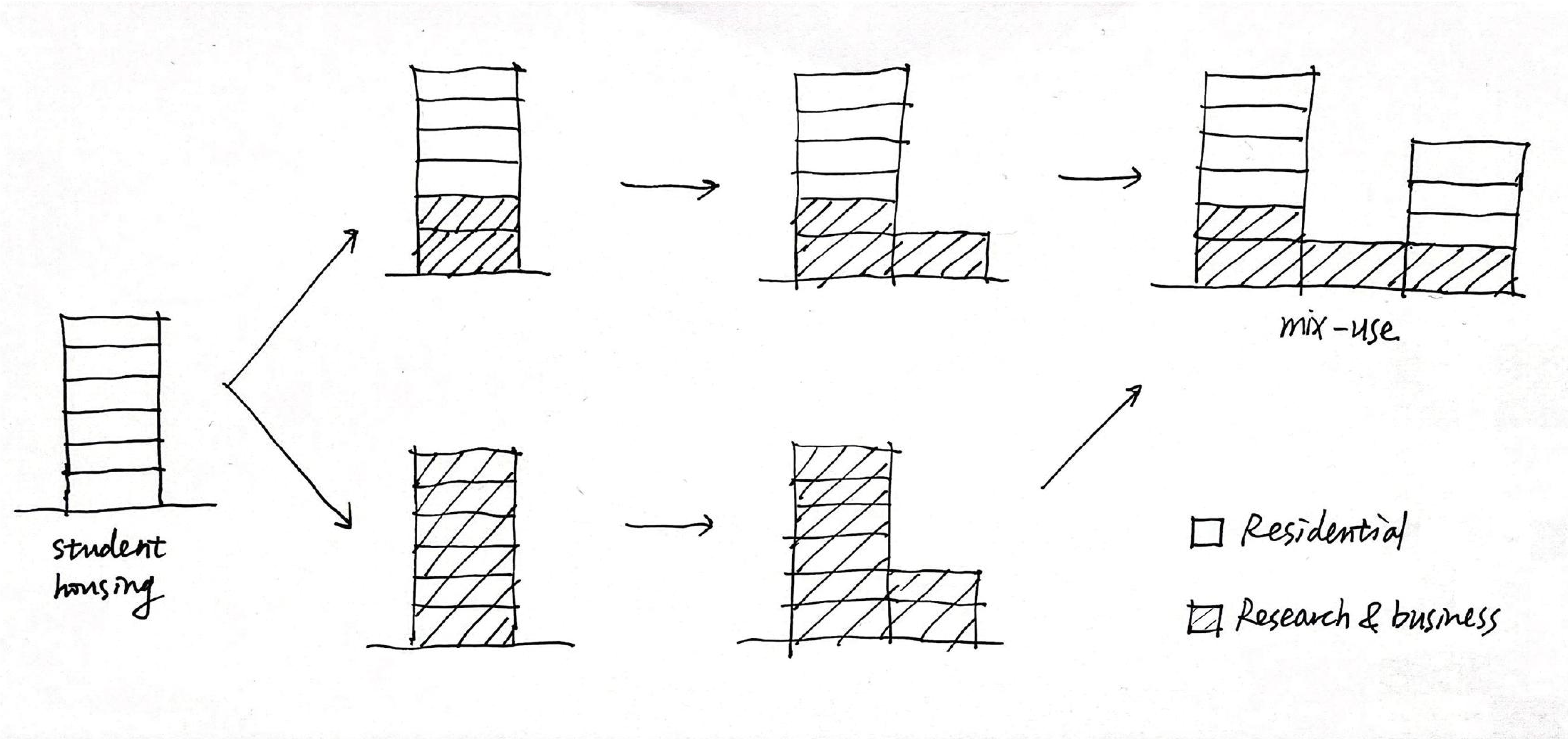


Figure 6. From a student housing towards a mix-use community (self made)

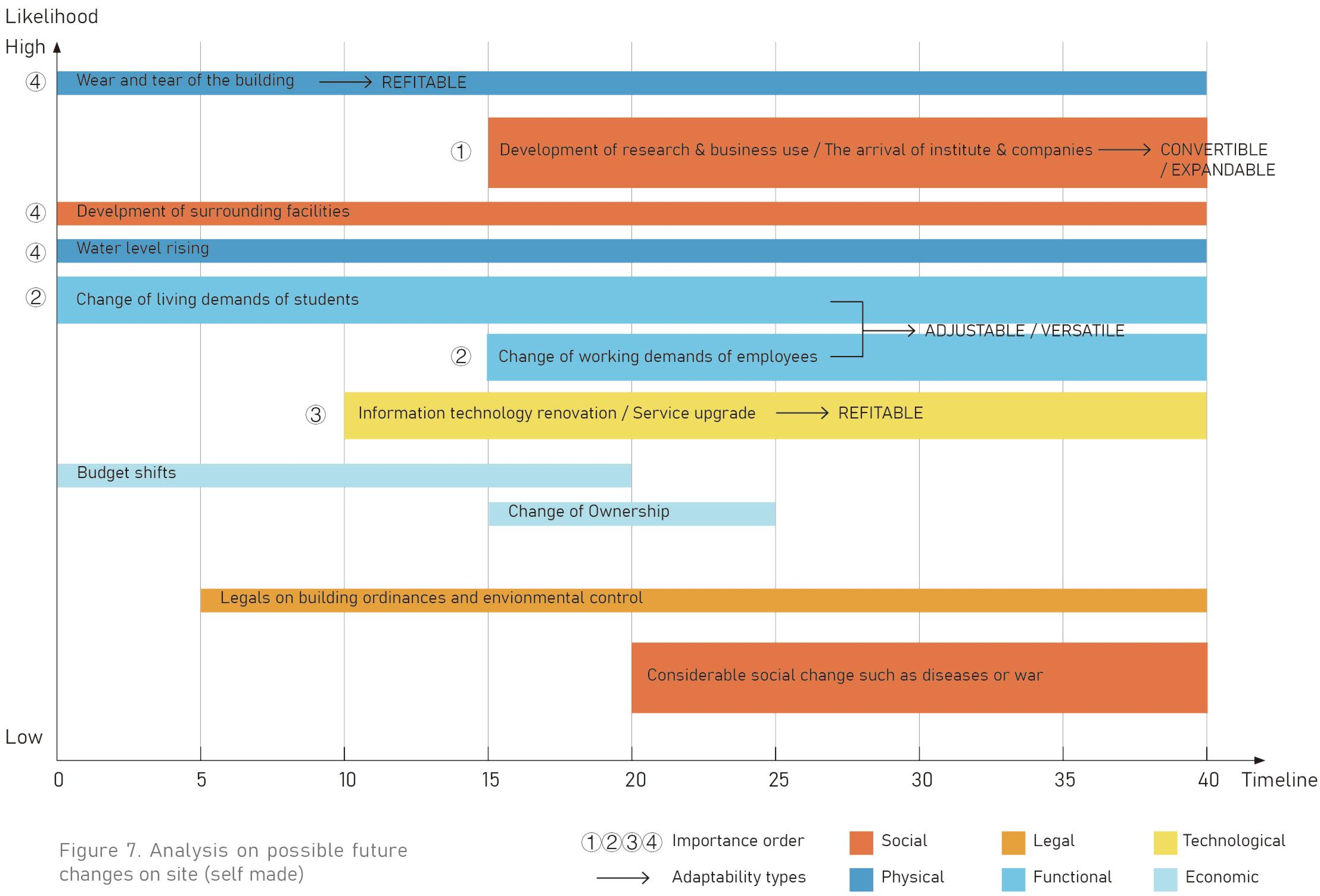


Figure 7. Analysis on possible future changes on site (self made)

THEMATIC RESEARCH QUESTIONS & METHODOLOGY

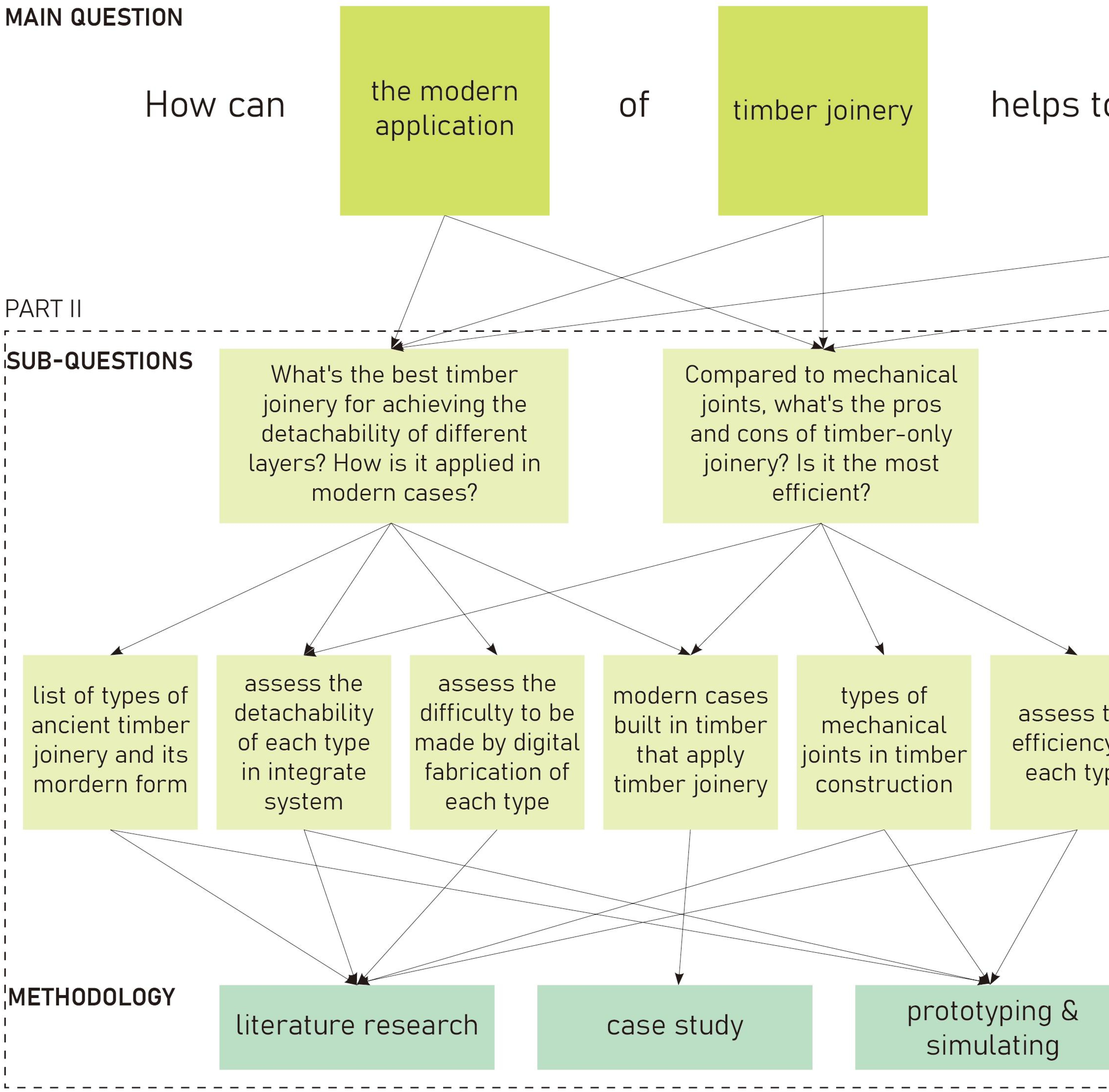
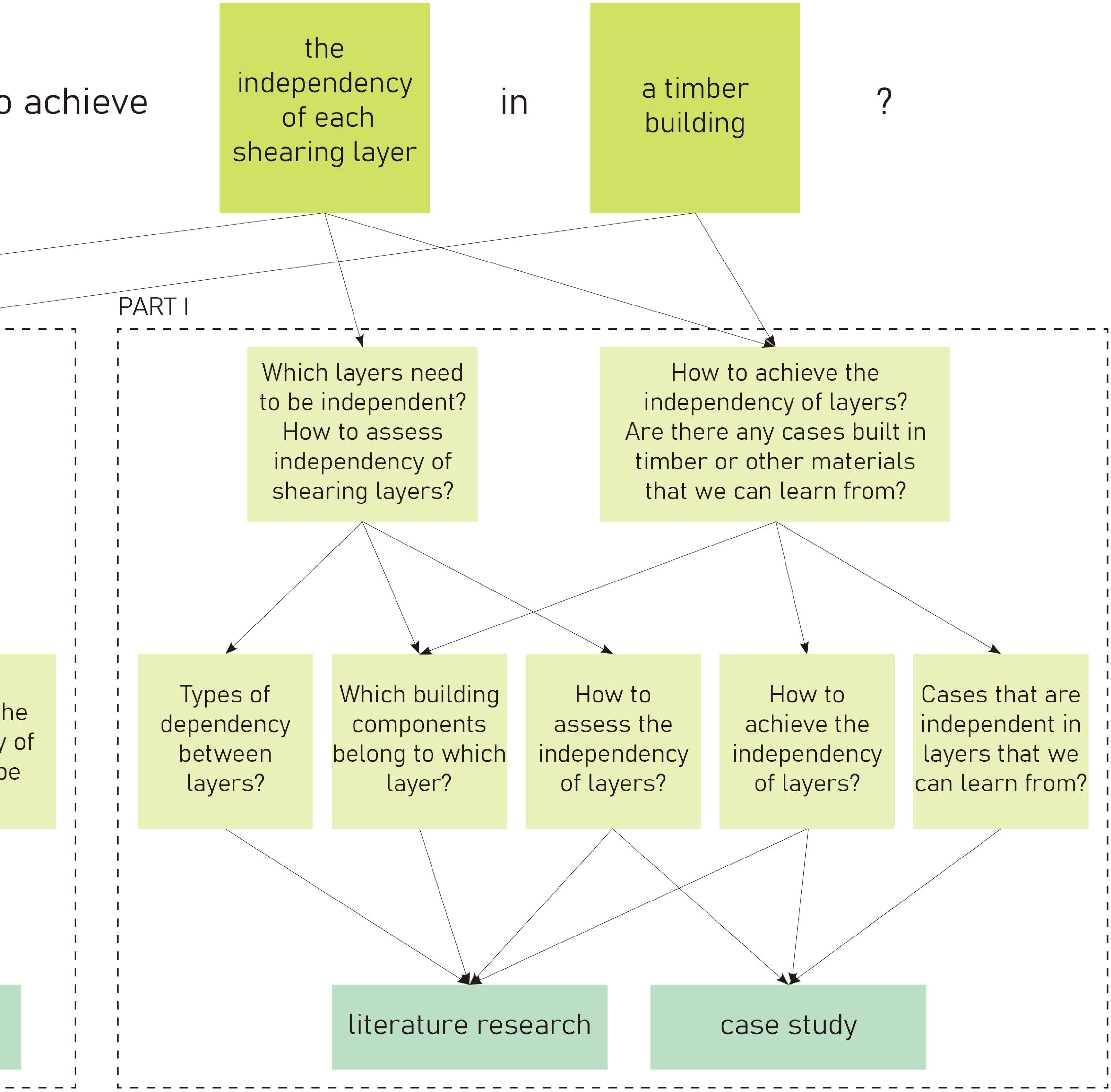


Figure 8. Research questions and methodology. (selft made)

HYPOTHESIS

There are some types of timber joinery that are easily demountable, and can be made by digital fabrication methods, suitable for achieving the independency of the shearing layers in timber buildings.



ANTITHESIS

1. Due to the inefficiency of the timber joinery, a mix-use of timber joinery technics and metal fasteners is allowed to achieve the detachability of the shearing layers in timber buildings.
2. Timber joinery is not suitable for achieve the detachability of the shearing layers in timber buildings, and other types of timber connection should be applied.

RESEARCH STRUCTURE & APPROACHES

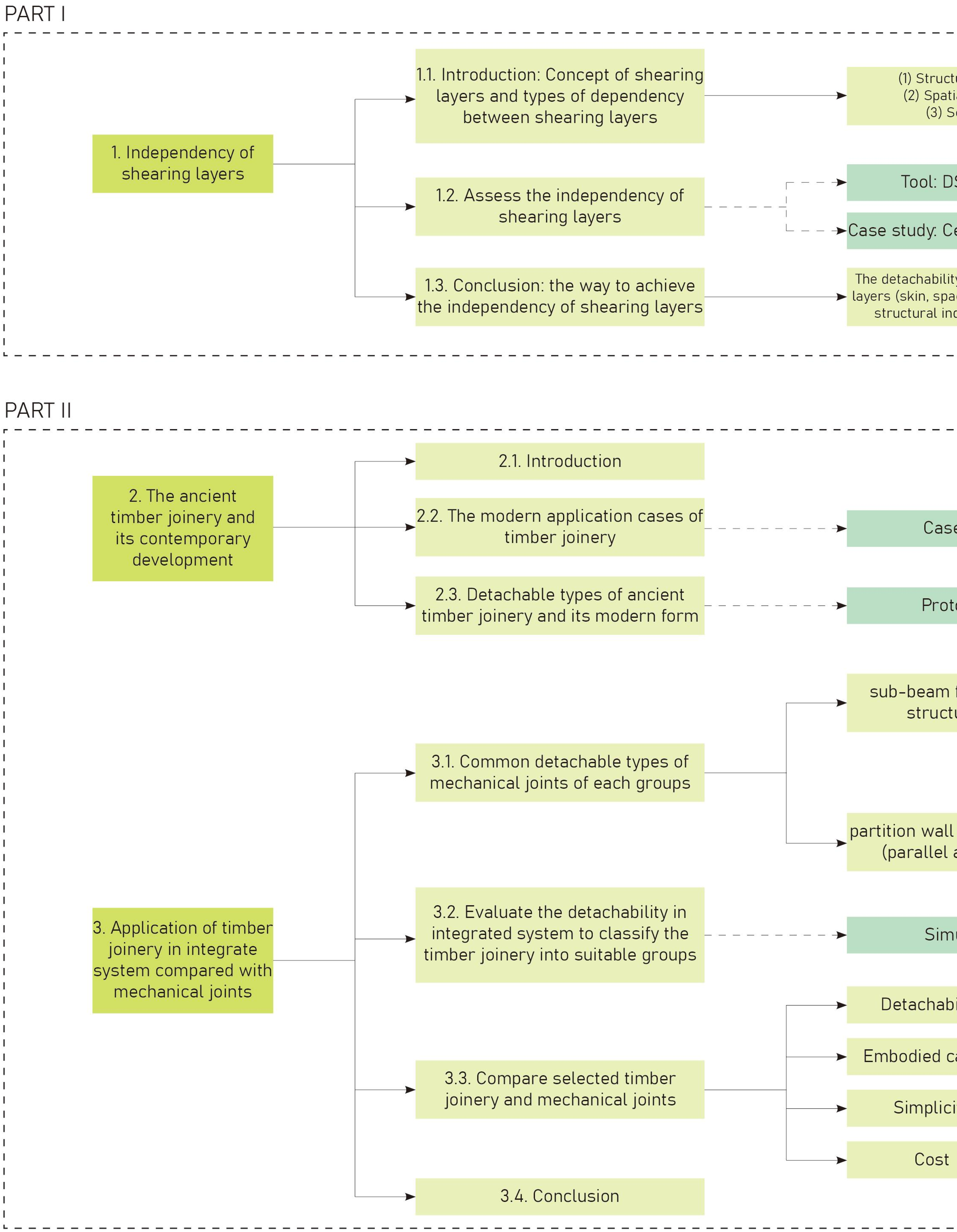
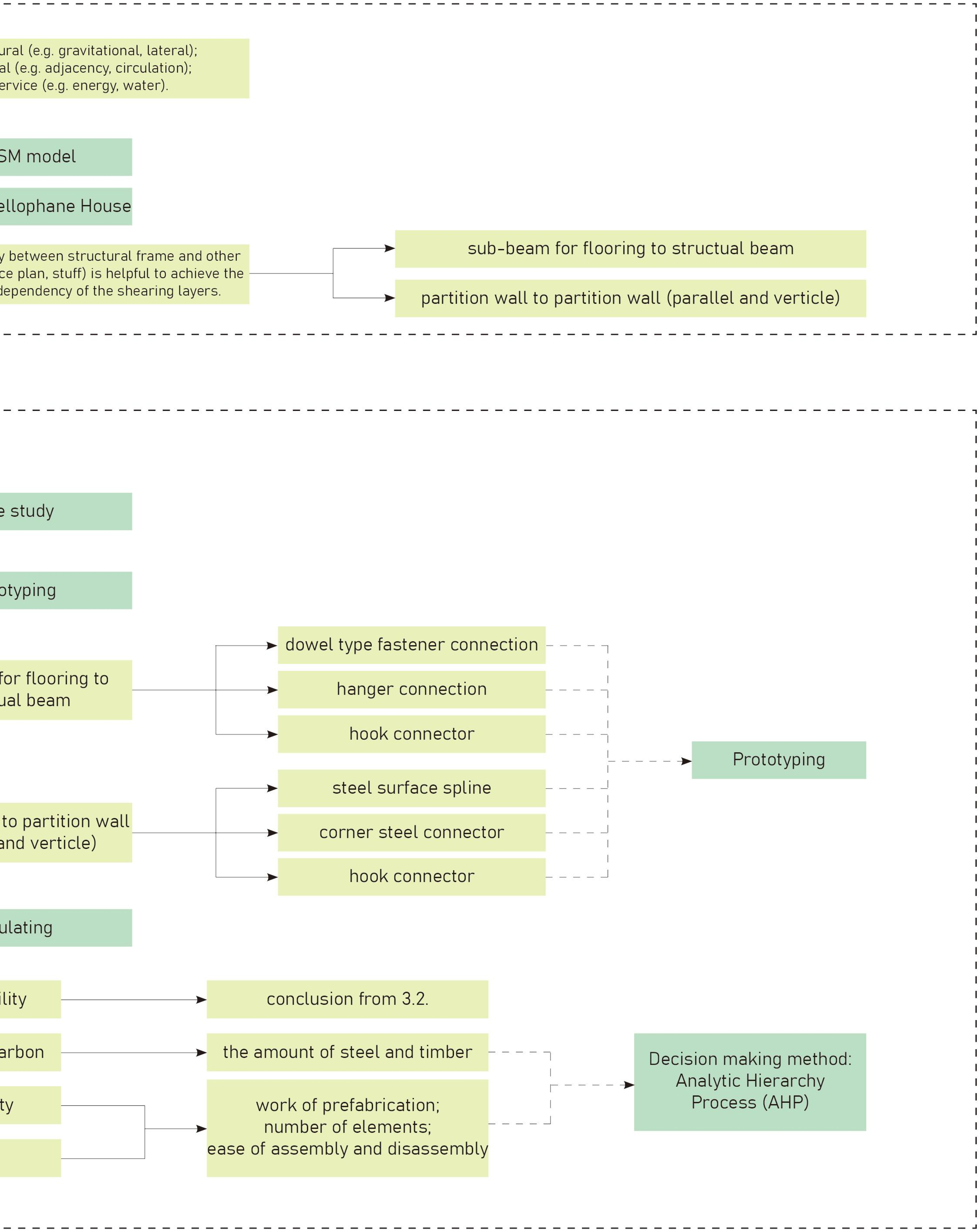


Figure 9. Research structure and approaches. (selft made)


ural (e.g. gravitational, lateral);
al (e.g. adjacency, circulation);
ervice (e.g. energy, water).
SM model
ellophane House
y between structural frame and other
ce plan, stuff) is helpful to achieve the
dependency of the shearing layers.
sub-beam for flooring to structual beam
partition wall to partition wall (parallel and verticle)
e study
otyping
for flooring to
ual beam
dowel type fastener connection
hanger connection
hook connector
to partition wall
and verticle)
steel surface spline
corner steel connector
hook connector
Prototyping
ulating
ility
conclusion from 3.2.
arbon
the amount of steel and timber
ty
work of prefabrication;
number of elements;
ease of assembly and disassembly
Decision making method:
Analytic Hierarchy
Process (AHP)

PART I

As shown in Figures 8 and 9, the research includes two parts. The first part investigates the following questions: Which layers need to be independent? How to assess the independency of shearing layers? Which building components belong to which layer? How to achieve the independency of layers? Are there any cases built in timber or other materials that we can learn from? The research on part I have already finished and helped narrow down the research topic of part II. The research process of part I will be simplified in the final paper, and the conclusion will be highlighted to be an important basement of part II. Firstly, the concept of the shearing layers and the types of dependency between the shearing layers (structural, spatial service) will be simply introduced. This paper will focus on the structural type of dependency between layers. In 1.2., the DSM model is found to be a useful tool for assessing the independency of layers. A case study of Cellophane House will be introduced to explain how the model works (Figure 10) and finally come up with a conclusion on how to achieve the independency of shearing layers. That is, the detachability between the structural frame and other layers (skin, space plan, stuff) is helpful to achieve the structural independency of the shearing layers. Then, two groups of position are picked out to be the field studied in part II, which are 'sub-beam for the flooring to structural beam' and 'partition wall to partition wall (parallel and verticle)' as shown in Figure 11. They are respectively about the connection 'between space plan and structure layer' and 'within space plan layer itself'. The reason why the components 'sub-beams for flooring' are divided into space plan layers is that they can be changed without having many influences on the main structure.

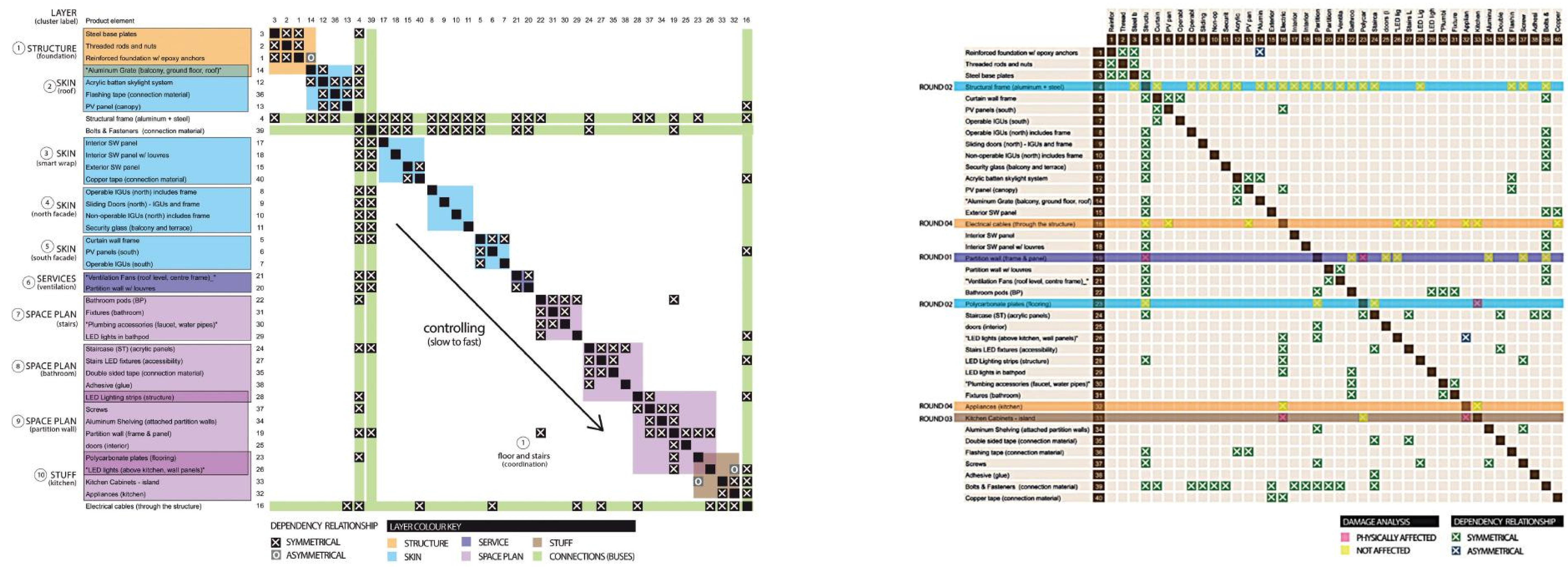


Figure 10. DSM analysis on Cellophane House (Schmidt, R., & Austin, S. A. ,2016.)

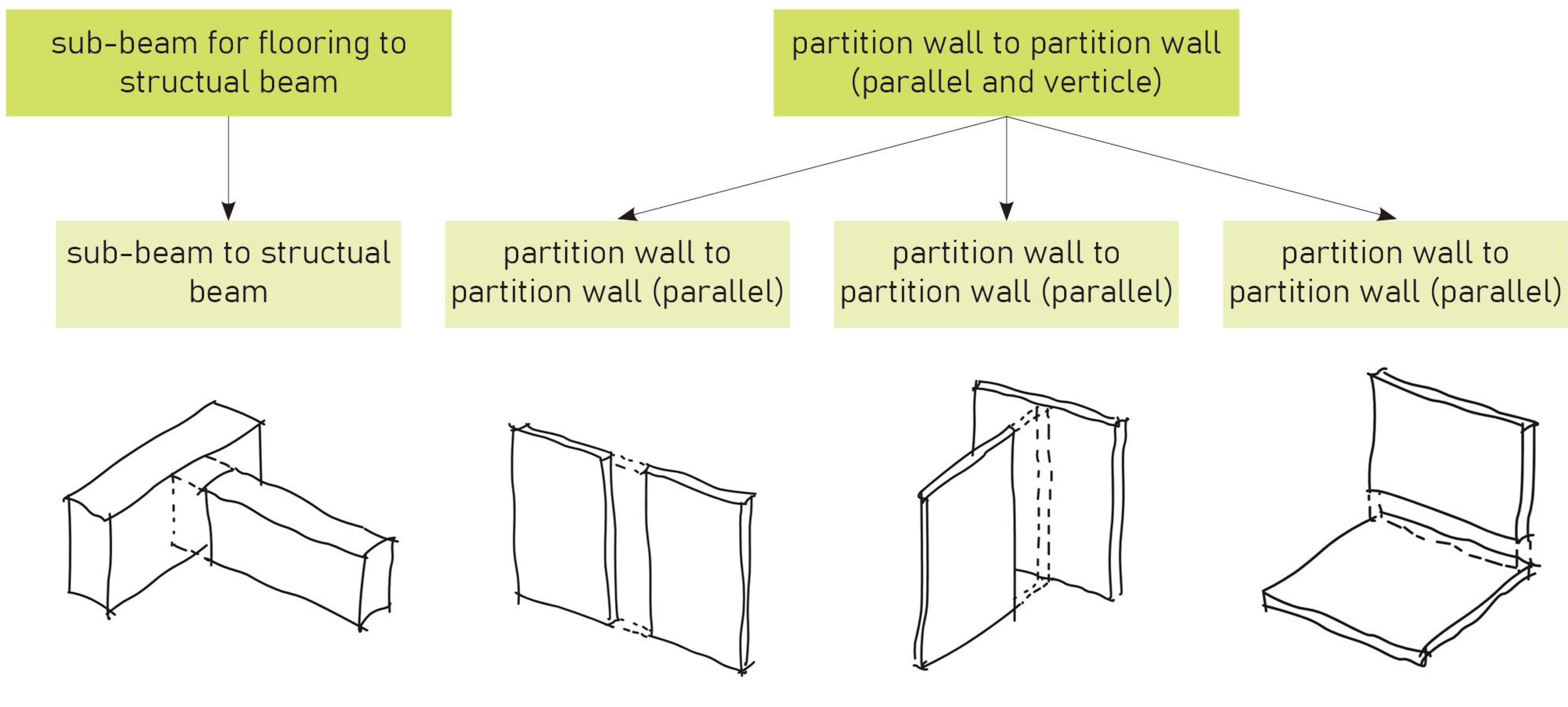


Figure 11. Groups for part II analysis (selft made)

PART II

Part II starts with research on ancient timber joinery and its contemporary development. Detachable types of ancient timber joinery need to be selected and prototyped because not all types of joinery are detachable. The modern application cases and digital fabrication methods of timber joinery will be studied, and the modern forms of the selected joinery types will be prototyped. The third chapter is the most important part of the research. It intends to compare the timber joinery with mechanical joints and find out the best types of each group ('sub-beam for the flooring to structural beam' and 'partition wall to partition wall'). Four criteria are considered, which are detachability, embodied carbon (affected by the amount of steel and timber), simplicity and cost (affected by the work of prefabrication; the number of elements; ease of assembly and disassembly). The detachability of joints will be evaluated in an integrated system rather than separately. In an integrated building system, some of the detachable joints may not be easily detachable anymore, due to the limitation of other building components. For example, in Figure 12, the internal wall cannot be taken out in a verticle direction because of the limitation of the flooring. Therefore, the dovetail joinery is not suitable for the connection between internal walls, but it can be used for the connection between the sub-beam and the structural beam.

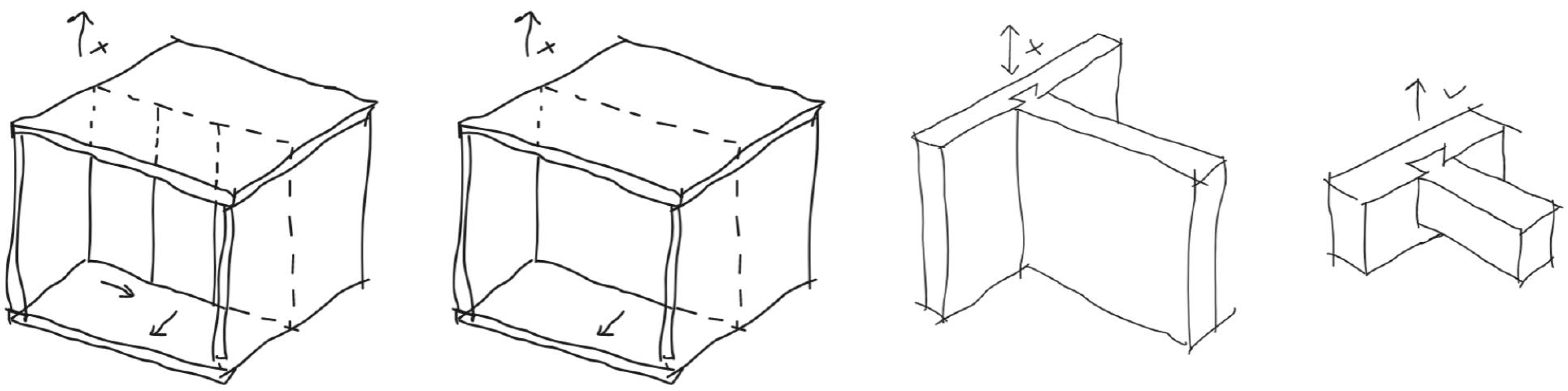


Figure 12. Example of detachability evaluation in the integrated system. (selft made)

For making the final decision considering all the criteria, Analytic Hierarchy Process (AHP) is a useful decision-making method. The AHP combines math and psychology to compare several options and select the best one. It does this by using a concept called pairwise comparisons, the process of comparing criteria two at a time instead of comparing several criteria at once. In this way, the choice is easier to make, and the evaluation of the weight of criteria can be objectively made without any bias. The AHP consists of four steps: (1) Identify the decision, options, and criteria; (2) Conduct pairwise comparisons; (3) Calculate the importance weight of each criterion; (4) Identify the best option by calculating something called utility.

	Detachability	Embodied carbon	work of prefabrication	number of elements	ease of assembly and disassembly	geometric mean (V)	Importance Weights (W)
Detachability							
Embodied carbon							
work of prefabrication							
number of elements							
ease of assembly and disassembly							

Figure 13. Sample of Analytic Hierarchy Process (AHP). (Jagoda, J.A., Schuldt, S.J. & Hoisington, A.J., 2020)

SCHEDULE PLANNING

WEEK	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
DATE	05-09 Sep	12-16 Sep	19-23 Sep	26-30 Sep	03-07 Oct	10-14 Oct	17-21 Oct	24-28 Oct	31-04 Nov
DEADLINE									
RESEARCH			DEVELOPING RESEARCH PLAN						
			PART I						
			LITERATURE READING & RESEARCH					CONCLUSION	
DESIGN			PROBLEM STATEMENT & CONCEPT DEVELOPMENT						
			RESEARCH & LITERATURE READING						

Figure 14. Schedule planning of MSc 3. (selft made)

WEEK	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
DATE	13-17 Feb	20-24 Feb	27-03 Mar	06-10 Mar	13-17 Mar	20-24 Mar	27-31 Mar	03-07 Apr	10-14 Apr
DEADLINE								P3 Progress review	
DESIGN	CONCEPT DESIGN								
	STRUCTURE & MATERIALS			PERFORMANCE					PERFOR
		PLAN & SECTION & FACADE 1:200							
	DSM MODEL			PERFORMANCE SIMULATING					PERFO
	DRAWING & DIGITAL MODELLING								

Figure 15. Schedule planning of MSc 4. (selft made)

MSc 3

1.10	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10
7-11 Nov	14-18 Nov	21-25 Nov	28-02 Dec	05-09 Dec	12-16 Dec	19-23 Dec	09-13 Jan	16-20 Jan	23-27 Jan	30-03 Feb
P1 Final research plan	No Education								P2 Final research paper	P2 Final research paper
PART II									CONCLUSION	
LITERATURE READING & PROTOTYPING					SIMULATING & COMPARISON					
	DEEPER ANALYSIS				DRAFT DESIGN (SPACE & PLAN)				P2 PREPARATION	
	DATA COLLECTION & ANALYSIS				SKETCH & MODEL					

MSc 4

3.10	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10
7-21 Apr	24-28 Apr	01-05 May	08-12 May	15-19 May	22-26 May	29-02 Jun	05-09 Jun	12-16 Jun	19-23 Jun	26-30 Jun
					P4 Final presentation					P5 Final presentation
DETAIL DESIGN				P4 PREPARATION		FINALIZATION & P5 PREPARATION				
MANCE OPTIMIZATION										
CONSTRUCTION DETAILS			FINAL WORK			PHYSICAL MODEL				
RMANCE SIMULATING										
DRAWING & DIGITAL MODELLING						MODEL MAKING				

RELEVANCE

With the development of the digital fabrication of timber, joinery has caught increasing attention from researchers. There have been some papers on the historical development, types and forms, and detachability of timber joinery, and also some of the papers compare the strength and embodied carbon of timber joinery with mechanical joints. The value of this research paper is to connect the modern application of timber joinery with the shearing layer concept of adaptability. Besides, it provides a new perspective on evaluating the detachability of joints in an integrated building system rather than considering them separately. It can further help select suitable joints in real design and construction.

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